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NATURE-STUDIES

BY

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AND

DALLAS

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NATURE-STUDIES:

By F. R. EATON LOWE; Dr. ROBERT BROWNE; GEO. G. CHISHOLM; JAMES DALLAS.

FLAME.

BY PROFESSOR F. R. EATON LOWE.

A BRILLIANT flame is the first object to fix the gaze of the young infant; and in manhood we still continue to feel a strange fascination under the influence of the same phenomenon. Even phosphorescence, unaccompanied as it is by flame, has an irresistible charm for us; while the vivid combustion of inflammable matter embodies a power and impetuosity which rivet the attention of the most stolid observer. We smile at the stupidity of the moth that singes its wings in the candle-flame; but there is within us a similar mysterious impulse that would impel us into the burning mass but for the consciousness of resulting injury, derived solely, as metaphysicians tell us, from knowledge gained by experience. Who is not struck with the splendor of a brilliantly lighted hall or theatre? Indeed, the beauty and luster imparted to large rooms by judicious lighting have no small share in the production of the vivacity felt by the audience generally. Turning to combustion on a large scale, with flames raging in uncontrollable fury, and material undergoing rapid destruction, there is probably no phenomenon in nature except, perhaps, the electric discharge, that impresses us with a stronger feeling of awe. A conflagration, from a bonfire to a building in flames, from a chimney on fire to a blast furnace belching forth its fiery tongues high into the air, is a fit emblem of ungovernable fury and relentless destruction. But it is more to our present purpose to regard flame as an instrument for good rather than evil. Most of the comforts and luxuries and even necessities of modern civilized life are due directly or indirectly to its agency; indeed, it would be difficult to name an art or manufacture which does not owe to flame its very birth. At home and abroad, in the house, the street, and the mart, we are surrounded by a multitude of substances which have been produced by the application of heat in one form or another. The spirit-lamp, the Bunsen burner, and the gas furnace, are the Alpha and Omega of the chemist's laboratory—the chief auxiliaries by whose magic power the multifarious compounds now become objects of commercial enterprise and sources of enormous wealth to the country, were originally prepared on a small scale. As a single example out of a thousand, take the manufacture of carbonate of soda from sea-salt more than 200,000 tons of which, of the value of two millions sterling, are annually made in the alkali works of Great Britain. The salt is first converted into sulphate of soda by the action of sulphuric acid; the sulphate of soda is then converted into carbonate of soda by being heated with chalk and carbon. This important substance was formerly manufactured from barilla; and the interesting chemical process now employed on so gigantic a scale was the result of

an experiment with substances heated in an evaporating dish by means of a spirit-lamp. Armed with his Bunsen burner the young chemist can produce a multitude of results not recorded in his books; and the present rapid growth of applied science affords him every encouragement to persevere in researches which may result in discoveries of public utility.

All life, vegetable and animal, on the surface of the globe, is sustained by heat emanating from flames existing in the sun's photosphere or luminous envelope. These "red flames," as they are termed, are visible only during a total eclipse of the sun, and are of inconceivable magnitude, shooting with tumultuous fury to a distance of about 30,000 miles from its surface. Of the nature of these gigantic flames we shall have more to say anon; we prefer to begin our investigations at home, and lighting the humble and antiquated tallow candle, study the chemical reactions concerned in its combustion. Here we must say a word upon combustion generally. All the ordinary sources of illumination, as tallow, wax, oil, and coal-gas, are kept in a state of ignition by the oxygen of the air. If we place our lighted candle at the bottom of a wide-necked bottle, it will soon be extinguished from the want of its powerful supporter.

The flame of an ordinary lantern or lamp, where a chimney is employed, would not burn more than a few minutes if holes were not provided at the base for the ingress of air. But for the occasional application of the poker, the combustion of a common fire would be maintained with difficulty, or prematurely put an end to, for the oxygen of the air must find free access to the interior of the burning mass, or the chemical decompositions we are about to describe cannot take place. On the same principle the best way of extinguishing fire is to smother it; that is, to cover it closely with something that will effectually cut off the source of its existence. If the clothes of some unfortunate friend should happen to catch fire, the best course to follow is to throw him down and envelop him in a rug, blanket, or anything of a similar kind within reach, when the flames will be immediaetly extinguished. To run about in search of water or assistance in these cases is simply to give time to the flames to reach a vital part of the body. But to return to our tallow candle, which is burning as brightly as can reasonably be expected from a consideration of the very small sum paid for it. If any prejudice against this humble luminary should exist in the mind of the reader, a glossy wax, paraffin or composite candle will do just as well. With the flame before us two questions arise with respect to it. Firstly, what is it that burns,—the wick, the tallow, or both? Secondly, What is the composition of the tallow? The existence of the flame depends entirely upon the combustion of the tallow, the wick being simply a vehicle for its ascent in the melted state. The closely twisted fibres of the wick constitute a number of capillary tubes; hence the liquid tallow is said to rise by capillary attraction (Latin, *capillus*, a hair).

The phenomenon in this case, however, is simply one of suction; for the ignition of the wick at starting causes the ascent of the air in the fine hair-like tubes, and the melted matter immediately rises to fill up the vacuum, and undergoes decomposition at the summit. Without the wick we should have a furious conflagration instead of the slow combustion of a continuous stream of inflammable liquid.

The wick, consisting of cellulose or woody fiber, is principally carbon or charcoal, and consequently chars or becomes blackened during combustion.

It is quite possible to construct a lamp without the aid of any wick at all. We once saw sold in the streets of London an ingenious device for a feeble nightlight at an almost nominal cost. It consisted simply of a wine-glass filled with oil, upon which was floated by means of a piece of

cork a small tin tube with a very narrow bore. On the application of a light to the tube, the oil rose by suction and became ignited. The whole cost of the apparatus, including a supply of oil, was one penny.

Before we can understand all about the combustion of our candle, we must learn something of its composition. Like the majority of organic compounds tallow contains carbon, hydrogen, and oxygen—the two first being essential constituents of all highly combustible matter of vegetable or animal origin, as wood, cotton, oil, wax, coal, turpentine, resin, and camphor. The difference in the composition of tallow and wax in 100 parts is given in the following table. A stearine or composite candle differs but slightly in composition from one of wax.

	Tallow.	Wax.
Carbon	77	80
Hydrogen	12	13½
Oxygen	11	6½
	100	100

During combustion these elements enter into new combinations with each other, and with the oxygen of the air, giving rise to a variety of inflammable gasses, the nature of which we must now investigate.

Looking attentively at our candle-flame, we shall notice that it comprises three portions of zones, a dark zone in the center, immediately surrounding the wick ; secondly, a luminous zone, from which its illuminating power proceeds ; lastly, a dimly perceptible external zone called the "mantle." In each of these areas special chemical reactions are taking place. The central zone is the *area of no combustion*, because the gasses evolved from the tallow do not meet with sufficient oxygen for their ignition. This fact can be proved by a very simple experiment. Insert a very narrow glass tube, or the stem of a tobacco pipe into the dark zone, and the unburnt gasses will be drawn off, and may be ignited at the other end.

Another proof that there is no actual flame in this area is furnished by the fact, that, if a match or grain of gunpowder is placed in its center, it will not be immediately ignited, but remain unconsumed till sufficient heat has been absorbed from the surrounding zone. The luminous zone is called the *area* of *partial* or *incomplete combustion ;* because here, the gasses meeting with an inadequate supply of oxygen, are only partially consumed, only part of the carbon is converted into carbonic acid; and the remainder floats about in a white-hot or incandescent state, producing the luminosity, without which the light would be valueless. The external zone or mantle is the *area* of *complete combustion*, because here, the gasses, meeting with the requisite amount of oxygen to oxydize the carbon and unite with the hydrogen are completely burnt; and as there is no solid carbon in this part of the flame, the light is very feeble.

Gasses Burning in the Candle Flame.—We have now to determine what are the gasses given off by the melted tallow or wax.

We have already stated that the elements of the combustible material enter into new combinations with each other and the oxygen of the air under the influence of heat. If we first draw off the gasses contained in the area of no combustion by the method just described, we shall be able to ascertain their nature, and then we can adopt a similar expedient with other zones.

The gaseous products found in the candle flame are carbonic acid, carbonic oxide, olefiant gas, and other hydrocarbons, including marsh gas, hydrogen, nitrogen, and aqueous vapor. It will be necessary to say a few words upon each of these bodies if the reader wishes thoroughly to understand the condition of things in this and other flames, for the combustion of coal-gas, oil, wood, and similar substances, is attended by similar phenomena, and the products of combustion are almost identical.

though differing considerably in relative proportion. One of the most important of these products is *carbonic acid*, or, as chemists prefer to call it, carbon dioxide, because it contains two atoms of oxygen united with one of carbon. It is thus distinguished from carbonic oxide, or carbon monozide, which has only one atom of oxygen to one of carbon. These bodies are conveniently written $C\ O_2$ and $C\ O$ respectively. As carbonic acid will not burn, it is evolved together with watery vapor, and enters the surrounding atmosphere. In these days of scientific progress every schoolboy is taught something of the properties of carbonic acid. He knows that it is a heavy gas, and, though invisible, can be poured out like water from one vessel into another. He knows, too, that it is one of the cast-off products of respiration, and, consequently, poisonous and irrespirable.

Notwithstanding this, we often take great precautions to prevent its escape. Scared by the ghosts of rheumatism and neuralgia, some people in winter close the doors of their apartments and stop up every crevice by which fresh air can enter or foul air escape.

By means of a sandbag at the window, another at the door, and a piece of list carefully tacked along its edge, the whole arrangement being supplemented by a screen, the products of combustion and exhalation are kept circulating in the room and breathed over and over again by those within, at the cost of morning headache, languor, and depression, with a long train of other evils following in the wake. From the fire, from the lights, and from the lungs of the inmates, the poisonous gas is evolved, and must be removed by efficient ventilation. We are here struck by the remarkable analogy between the process of combustion and the function of respiration.

The latter is, in fact, a species of combustion without flame. The carbon of the impure venous blood unites with the oxygen of the air to form carbonic acid gas, while the hydrogen unites with another portion of oxygen to form water. Both products are expelled at each exhalation, and the chemical action going on within the body raises its temperature to nearly 100°. To prove the presence of carbonic acid in our candle flame, we have only to siphon it off by a bent tube, and pass it into lime water, which will become milky owing to the formation of carbonate of lime or chalk. In the same way we can show the presence of carbonic acid in the breath on simply blowing down a tube into lime water (made by shaking up powdered quicklime with *distilled* water) an immediate precipitate of carbonate of lime will be produced. We all know that aqueous vapor is exhaled from the lungs.

To show its production in our flame invert over it a dry tumbler. In a few seconds the interior will be covered with moisture owing to the condensation of the vapor. *Carbonic oxide* differs from carbonic acid in being combustible, and is, therefore, consumed in the flame. In burning, however, it takes an atom of oxygen from the air, and produces $C\ O_2$ or carbonic acid. It is this gas which burns with a blue flame at the top of our coal fires. The carbonic acid formed at the bottom of the grate, loses half its oxygen in passing upward through the red-hot coals and again reverts to its original condition on combustion. There is consequently no destruction in nature.

What appears to be lost simply assumes another form, and passes into the atmosphere to play another and more important part. What is rejected by man and animals as a poison is the very pabulum of plants, and the chief source of their substance.

Olefiant Gas is an important ingredient in our candle or gas flame, as it is the chief illuminating agent. It is sometimes called heavy carbureted hydrogen, and its formula is written $C_2\ H_4$. Its name—olefiant (oil-mak-

ing), was given to it on account of the oily liquid which it forms when combined with chlorine.

These compounds of carbon and hydrogen are called *hydrocarbons*, and constitute a very large class. Some of them are solid, as paraffin and naphthalin; others liquid, as turpentine, petroleum, benzol and camphine; and others gaseous, as marsh gas and olefiant gas. As may be expected from their composition, these hydrocarbons are highly inflammable, and burn with a more or less smoky flame in proportion to the amount of carbon they contain. Those which contain the largest number of atoms of carbon capable of uniting with hydrogen, such as paraffin, are called *saturated hydrocarbons*. Paraffin candles are made of a mixture of paraffin and wax, and give a very fair light, because several other "olefines" besides olefiant gas are present in the flame. The illuminating power depends upon the separation of carbon in the solid form, and its incandescence in the zone of incomplete combustion. Olefiant gas, like carbonic oxide, produces carbonic acid by its combustion. We shall describe an easy method of preparing it in the pure form when we come to speak of flames of special interest.

Marsh Gas.—This gas which burns in coal-gas flame as well as in our candle flame is so called because it occurs in nature over stagnant pools and marshes, having been formed by the decomposition of dead leaves and other vegetable matter. It may be collected from these pools by stirring up the mud at the bottom and receiving the bubbles of gas in an inverted bottle filled with water. Marsh gas or light carbureted hydrogen, $C\ H_4$, constitutes the "fire-damp" of coal mines, issuing sometimes in enormous quantities in "blowers" from the coal seams. This gas, like the other hydrocarbons, forms carbonic acid and water by its combustion with oxygen.

Hydrogen.—This is the lightest gas in nature, its weight being one-fifteenth that of common air, on which account it is used for filling small balloons. It forms an explosive mixture with air; and as it is found free in coal-gas it becomes an element of danger wherever there is an escape from the pipes into a closed apartment.

Coal-gas Flame.—The bodies whose properties we have thus briefly summed up are found in coal-gas, the flame of which does not differ much in its chemical reactions from that of a candle. The gas, however, differs much in composition and illuminating power in different towns, the proportion of its constituents varying with the quality of the coal employed, and the temperature to which the retorts are raised. Sometimes the purification of the gas is incomplete; some of the products of the distillation, such as carbonic acid, sulphureted hydrogen, and di-sulphide of carbon, are not only valueless as illuminating agents, but communicate to the gas a disagreeable odor, and must therefore be removed before the gas passes into the gasometer.

These sulphides produce by their combustion sulphurous acid—a gas of a pungent suffocating character; and if present at all in coal-gas may be detected by the application of lead paper, or paper impregnated by a salt of lead. The paper will become blackened by the formation of lead sulphide. The following table represents the composition of coal-gas of good quality:—

Marsh Gas	41·88
Hydrogen	41·71
Carbonic Oxide	4·98
Olefines	8·72
Nitrogen	2·71
	100

In some samples we have found no nitrogen, the whole of that element having united with hydrogen to form ammonia, one of the secondary products of the gas manufacture. The composition of different parts of a coal-gas flame has been examined by

Professor Landolt, who gives us the following results :—

Height from Burner in inches . .	0·	0·39	07·9	1·18	1·58	1·97
Total volume of Air and Gas before burning . . .	127·08	145·43	272·76	327·73	43·53	481·66
Total volume of Gas after burning .	111·41	120·09	245·96	311·37	422·59	461·23
Hydrogen .	22·66	14·95	5·49	15·54	14·5	11·95
Marsh gas. .	33·77	30·2	28·34	21·55	11·92	3·64
Carb. oxide .	7·34	14·07	14·05	14·58	22·24	25·14
Olefines . .	7·29	7·49	7·87	7·94	7·05	5·45
Oxygen. . .	0·66	0·78	0·47	....	..	....
Nitrogen . .	29·41	38·66	140·7	184·23	270·45	307·1
Carbonic acid	1·94	2·34	10·11	14·98	23·76	32·34
Water . . .	8·34	11·6	38·85	52·58	72·67	75·61

In the column marked "0· *inches*" we have the proportion of gases occurring immediately in contact with the wick, and the distances increase up to 1·97 in., which may be taken as two inches. We find the quantity of hydrogen decreasing up to 0·79 inches, when there is a sudden increase, owing, probably, to its liberation from the watery vapor by the action of the highly-heated carbon at this point. It will be noticed that the quantity of water rapidly increases toward the summit of the flame, where it passes out into the air. A similar increase is observable in the case of the nitrogen, derived from the decomposition of the air, the oxygen of which combines with the carbon and hydrogen to form corbonic oxide, carbonic acid, and water. The nitrogen is an inert body, and does not combine with any of the gaseous matters in the flame; it therefore escapes unchanged. It will be seen that there is no uncombined oxygen above 0·79 in. The increase in carbonic oxide is due to the action of the highly-heated carbon on the carbonic acid, $C\ O_2$, which parts with one atom of oxygen and becomes C O.

Cause of Luminosity in Flame.—We have already stated that the presence of solid carbon in a white-hot state is the cause of luminosity in flame generally. Davy proved this by bringing into contact with the flame a cold substance, when a deposition of soot or carbon was the result. The chemist is acquainted with brilliant flames in which there is no solid matter; but as a general rule the presence of such matter considerably increases the illuminating power. If we project air or oxygen into a flame we destroy its luminosity by dispersing the luminous matter over a wider area, and thereby facilitating the conversion of the carbon into non-luminous gases. We are all familiar with the spluttering blue flame sometimes produced when we first light the gas, in consequence of the admixture of air in the pipes. The reduction of temperature which takes place in this case has much to do with the phenomenon, for we shall presently show that the introduction of nitrogen, steam, or any gas exerting no chemical action on the flame, destroys its luminosity as completely as oxygen. If the air or gas to be passed into the flame is first heated the luminosity at once returns.

It is therefore obvious that the old theory supported by Davy and maintained by other chemists almost up to the present time, respecting the connection between oxygen and flame luminosity, requires modification. The effect appears to be quite as much due to the nitrogen, which, as a reference to the table just given will show, is given off in gradual increasing quantities, and assists in reducing the temperature. The effect produced by mixing air with coal-gas is well seen in the Bunsen burner, which has almost superseded the spirit-lamp, and is universally used in the laboratory for heating flasks, retorts, air baths, etc. It consists of an ordinary gas-burner surrounded by an iron cylinder. At the base of the cylinder there are holes for the admission of air, which rises with the gas to the summit, where the mixture is burnt. The flame is non-luminous, and is not only hotter than an ordinary flame but has the advantage of not blackening the apparatus heated

by it. If we stop up the holes at the base, which can be effected by simply turning the cylinder round, the unmixed gas alone rises, and the flame becomes luminous. That this flame is hollow like that of a candle can be shown by passing into its center a match, which will not ignite at once, and also by bringing rapidly down upon it a piece of stout white blotting paper, which will exhibit on withdrawal a charred ring.

The effect of nitrogen or steam upon the non-luminous flame may be tried in the following way :—stop up one of the air holes with a cork, and into the other fix a tube communicating with a gasholder containing nitrogen gas.

The passage of the air being cut off, the flame burns with a bright yellow light, but as soon as the nitrogen gas is allowed to mix with the coal gas, the flame becomes blue and non-luminous. Instead of nitrogen we can send into the burner a current of steam from a flask of boiling water when the same effect will be produced. Conversely we can render a non-luminous flame luminous by raising the temperature of the nitrogen before its introduction into the burner. This can readily be done by fitting a metal tube into the air-hole and connecting it with the delivery tube of the gas-holder. The tube being heated by a lamp placed below it, the temperature of the nitrogen is raised and the flame immediately becomes luminous. Dr. Frankland's recent investigations on the nature of flame have led him to the conclusion that the luminosity of flame is not due to solid carbon, but to a mixture of hydrocarbons capable of condensation like water from steam.

The increase of brilliancy imparted to flame by the presence of incandescent solid matter can be illustrated in various ways. The well-known experiment, so familiar to young chemists, of burning phosphorus in oxygen furnishes an excellent example. When the ignited phosphorus is passed into a jar of the gas by means of a deflagrating spoon, the whole vessel is filled with a most dazzling white light, owing to the dispersion of solid phosphoric acid, $P\ O_3$, produced by the union of the two elements.

When sulphur is burned in the same gas, the blue flame which is produced has not the same luminosity, because the product, sulphurous acid, S O, is not solid but gaseous. The combustion of magnesium affords another illustration of the same principle. The intense white light emitted is due to the presence of solid particles of incandescent magnesium oxide or magnesia when metalic zinc is melted in a crucible, a beautiful luminous flame is seen to play over its surface owing to the formation of solid oxide of zinc in woolly flakes; hence in this state it was formerly known as

"*Philosopher's Wool.*"—The oxyhydrogen flame is scarcely visible in daylight; but if allowed to impinge on a ball of lime to produce the "lime light," we get one of the most brilliant and luminous flames with which we are acquainted. Coal-gas is now usually employed instead of pure hydrogen to mix with the oxygen. In the production of this light the oxygen must be kept in a separate bag, and allowed to mix only with the coal-gas in the burner, which must be of peculiar construction, otherwise the flame might pass down the tube and give rise to a violent explosion.

A safe and easy method of showing the lime light is to fill with oxygen a bag to which a brass cap and long nozzle is fitted, and to force a stream of the gas through a hydrogen flame issuing from a glass tube attached to the bottle in which the hydrogen is prepared. The flame is allowed to impinge upon a cylinder of lime, and intense ignition follows. The cheapest, and perhaps the safest jet that can be used for the lime light is Tate's. It consists of a cylinder of japanned tin plate, six inches high and two inches wide, closed by a cork at its upper end, and standing upon a heavy foot. The blow-pipe jet is con-

nected with a tube filled with several pieces of wire-gauze to prevent the passage of the flame into the cylinder. The gas delivery tube brings the mixed gasses from the reservoir into the cylinder which is filled with water to within an inch of the cork. The tube is closed at its lower end by a valve of silk. If from any imperfection in the gauze packing the flame should happen to pass into the space below the cork, the small quantity of gas enclosed therein will explode with no other result than the expulsion of the cork.

The gasses pass into the burner from separate reservoirs through the tubes, and the supply is regulated by stopcocks. There is a movable stand for the support of the lime cylinder. By means of a screw the table upon which the burner and lime stand are fixed may be turned in any direction.

Dr. Frankland has pointed out certain other causes which affect the luminosity of a flame, as the degree of condensation suffered by the burning body and the relative weight of the products of combustion. Thus the flame of alcohol is but feebly luminous under ordinary circumstances, but becomes much brighter in condensed air. The same phenomenon is observable with the oxy-hydrogen flame under pressure. A candle burns with a less luminous flame at the top of a high mountain than it does in the plain below.

As the amount of oxygen in a given volume of air increases with the density, these cases seem to involve a reversion of the law already laid down with respect to the cause of luminosity generally.

The effect, however, is due to the compression of the luminous material into a smaller compass. Similarly with regard to the products of combustion, the higher their density the brighter the light emitted. Thus hydrogen burns in oxygen with a flame of little luminosity, but its combustion in chlorine is more vivid. The product in the first case is water, H_2O, and in the latter, hydrochloric acid, HCl, the specific gravities of which are respectively 1000 and 1210. We have already referred to the effect produced upon flame by the presence of heavy olefines or hydrocarbons. This action has been taken advantage of in the construction of the new "hydrocarbon" lamps, in which coal-gas is saturated with the liquid hydrocarbon before its ignition. The gas on its way to the burner passes through a ball containing pieces of paraffin kept in a melted state by a small jet underneath. It thus becomes enriched with carbon, and gives a flame of great illuminating power. This lamp has been introduced into some of our places of amusement, and is certainly one of the most effective and convenient forms of illumination for large buildings at present in use. The gas companies, put upon their mettle by the triumphal march of the electric light, have recently turned their attention to the improvement of the burners, and have devised some very effective street lamps, well adapted for central positions. The burners are constructed on the principle of the Argand lamp and Berzelius spirit-lamp, in both of which circular wicks are employed, so as to permit the passage of air through the center of the flame thus securing a more perfect combustion. The burners consist of two or three concentric rings, producing the same number of hollow cylindrical flames, and being surmounted by a conical reflector, a powerful flood of light is diffused below.

The illuminating power of coal-gas is generally estimated in candles; the gas burning at the rate of five cubic feet per hour being compared with a sperm candle burning 120 grains per hour. Thus an ordinary coal-gas flame is equal to fourteen candles, but there is much variation in this respect, the cannel coal used in some parts of Lancashire giving a flame of thirty-four candle power. The light of some of the new concentric burners is said to be equal to that of 200 candles.

Flame and Conduction.—If we with-

draw heat from a flame by means of a good metallic conductor, combustion becomes imperfect, if not altogether suppressed. The heavy hydrocarbons become condensed, and solid carbon is rendered visible as a cloud of smoke. Thus, if a coil of cold copper wire is held over a small flame it is extinguished; and an iron spoon placed upon the apex will produce a stream of dense black smoke. A striking experiment in illustration of this can be performed with a Bunsen burner and a piece of fine wire-gauze having about 700 meshes to the square inch. The gas is turned on but not ignited, and the sheet of gauze held over it about an inch from the top. The gas will pass through, and may be inflamed on the upper surface, but no flame will be visible below, because too much heat is withdrawn by the metal. The gauze may be moved upward to the extent of another inch or two and the flame will be lifted with it, till the large admixture of air extinguishes it. On this principle Davy constructed his famous safety-lamp, which has done such useful service to miners. The lamp is surrounded with wire-gauze through which the fire-damp enters and is inflamed within; but heat being withdrawn by the metal, the mass of inflammable gas without cannot take fire, and thus the miner has time to make his escape before the gauze becomes red hot.

Modifications of Bunsen's Burner.—Since the invention of Bunsen's burner numerous modifications have been employed for heating purposes, not only in the laboratory, but in the arts and manufactures. In the "gauze top" burner the cylinder is two inches in diameter, and covered with a sheet of wire-gauze. The mixture of gas and air passing through the gauze is ignited and gives a large flame of great power suitable for heating crucibles, large evaporating dishes, etc. In what are called *solid flame* burners, the diameter of the gauze is increased, so as to produce a flame six or eight inches across, and capable of boiling several pints of water in a few minutes. Furnaces for fusion, assaying, and metallurgical purposes, are formed of a combination of burners. They are placed in close contact, and the heat of the flame is augmented by the aid of a blowing machine worked by a treadle. Griffin's blast gas furnace made upon this principle, is capable of melting thirty-two ounces of copper or cast-iron in ten minutes.

In Hofmann's furnace for heating combustion tubes, there are as many as 170 Bunsen burners in two parallel rows, and placed so closely together as to give almost a continuous line of blue flame.

Olefiant Gas.—As olefiant gas and similarly constituted bodies are the chief illuminating constituents of coal-gas, it may not be out of place to give the reader a description of some experiments illustrating the nature of heavy carbureted hydrogen in a state of purity. Its preparation is very simple. Pour into a flask a mixture of two ounces of alcohol or methylated spirit and the same bulk of strong sulphuric acid. Close the flask with a cork through which is passed a narrow glass tube. A gentle heat is applied by means of a spirit-lamp or Bunsen burner; and when the gas is given off, it may be ignited at the orifice of the glass tube. A large luminous flame upward of a foot in length will be thus produced. It may be useful to compare this flame with that of ether under similar circumstances. A little common ether is to be placed in a small flask fitted in the same way as in the previous experiment. On the application of a very gentle heat, vapor will be given off abundantly, and yield, on ignition, a flame nearly a yard in length. A jar of the gas may be collected at the pneumatic trough by using a retort or a flask fitted with a glass tube bent at an acute angle. The jar is to be turned mouth upward, and the gas inflamed, when it will burn with a large, smoky flame, the size of which may be considerably increased by pouring in water from a jug or beaker, the effect of

which is to drive the gas out of the jar. To show the presence of black charcoal in this gas, one volume of it is mixed with two volumes of chlorine in a tall jar, and inflamed. A dull lurid flame will pass slowly down the jar, while a dense volume of black smoke will be given off. The student should be careful to make this mixture at night, as it is liable to explode spontaneously in sunlight. Olefiant gas mixed with three times its volume of oxygen explodes violently when inflamed; and coal-gas mixed with ten times its volume of common air is similarly explosive; hence the necessity for caution when an escape of gas into an apartment is observed.

The Blowpipe Flame.—When the flame of a Bunsen burner is acted upon by a blowpipe, it divides itself into two portions, one within the other, called the reducing flame and oxidizing flame respectively. In chemical action these flames are opposed to each other, one imparts oxygen to a metal subjected to its influence, while the other abstracts oxygen from an oxide, and reduces the metal. The inner flame is the reducing flame, because here there is excess of carbon, which unites with the oxygen of an oxide exposed to it. The outer flame is the oxidizing flame, because here the heated oxygen tends to unite with any metallic body exposed to it to form an oxide.

These reactions are of the greatest importance in chemical analysis. A fragment of the solid to be tested is placed upon charcoal and heated by the blowpipe; in a few seconds, if the substance is a metallic salt, little globules of metal will make their appearance, the nature of which can readily be determined.

Colored Flames.—Certain vaporisable salts communicate color to flame by being carried up with the heated gasses, as in the process of sublimation. Thus salts of strontium communicate a red color, salts of copper a green color, sodium salts yellow, and potassium salts a violet tinge. These colorations are best shown by saturating alcohol or methylated spirit with the respective salts and setting it on fire. A striking experiment known as the "*Fire cloud*" is performed as follows:—Dissolve in a pint of methylated spirit five parts of chloride of strontium, and one part of nitrate of copper, or boracic acid. The mixture is to be projected with some force upon the ceiling of a room by the aid of a syringe or metallic fountain, in which the air can be condensed. The spirit being inflamed a brilliant cloud of variegated fire will be produced. The experiment is free from danger, as the combustion is too rapid to cause ignition of the wood-work. It should be noted that methylated spirit is not so well adapted for showing these colored flames as pure alcohol, as it burns with a yellowish flame, in consequence of the smaller portion of carbon in its composition.

The flame of pure spirit (ethyl alcohol) is pale blue, a tint which permits the red and green flames to show in stronger relief. An expeditious method of conducting the experiment is to ignite the spirit in a saucer or evaporating dish, and then to throw into the flame the various salts in fine powder.

The violet tint of potassum and the yellow of sodium are best shown by using the metals themselves. A fragment is simply to be dropped into water, which, in the case of sodium, must be hot.

Our space is now exhausted, but the field of research opened up by our subject is inexhaustible. Flame was the mighty Frankenstein to whom the old alchemists looked for aid in their visionary schemes of transmutation; but since the time of those assiduous but misguided philosophers, flame has worked greater wonders than ever entered into their wildest fancies. The diligent experimenter may be assured that much still remains undisclosed, and that by means of the Bunsen burner, blow-pipe, and blast-gas furnace, discoveries have yet to be made which will, at the same time,

startle and benefit the world. Our experiments, however, must not be simply tentative; they must be begun, continued, and ended in accordance with physical laws, which will never change, whatever may be the ultimate revolution in scientific theories. By heat the elements can be separated, and by the same agency they can be combined; the more perfect, therefore, our knowledge of chemical action and reaction, the more likely are our researches to terminate in satisfactory results.

BIRDS OF PASSAGE.

By Dr. Robert Brown, F.L.S., etc.

The least observant person who walks even a short distance beyond the range of bricks and mortar cannot fail to notice that in early spring a strange uneasy movement seems to pervade every living thing. Nature appears to have woke out of a long sleep, and now, after the torpidity of the winter, is resuming the active existence which was suspended in October. Hardy flowers are springing up in sunshiny spots, and the gay catkins of the willow and alder are braving the east winds even before the leaves have expanded. The buds are bursting visibly, and even audibly; the butterfly has left its chrysalis; and the cautious snail, which for months past has heen hybernating in a snug hole in the wall, is preparing to taste the tender herbage beginning to sprout above the half-thawed soil. In evening, provided the day has been warm, the insect life sufficiently plentiful, the bats may be seen flitting round the old barn in which they have been passing the idle season, and a sharp eye may easily enough detect among the dead leaves the harvest mouse and other little mammals, which are for the first time venturing abroad in the hope of finding provender enough to reward their temerity. Even inanimate nature is bestirring itself. The brooks are noisy with the melting snow of the still snow-capped hills, and the drip, drip, which, according to the Roman poet, wears the stone not by force, but by often dripping, seems to supply an accompaniment to the general stir which is proceeding apace.

But what betokens the arrival of spring even more than the crawling of snails or the flutter of insects is the arrival of the migratory birds. That they are migratory is to most of us a matter of such familiar knowledge that we no more think of questioning it than we conceive it necessary to doubt the rotundity of the earth or the waning of the moon. We know that certain feathered friends are here during the summer, and it is equally certain that they are absent a few months later, only to appear with the first flowers and the pioneer bees. In March—and sometimes even earlier—the chiff-chaff, the pipits, and the wheatear, appear respectively in copse, on the river bank, and open commons and deserted wastes. By the first week in April the whin-chat and the stone-chat are hopping about the last-named locality; then the hedgerows appear peopled as if in a night with willow warblers, while fruit trees attract the black-cap, the wood warbler and the white-throats. The season must be a late one if the cuckoo is not heard by the middle of the same mohth, while the nightingale, which is so chary of extending her range beyond a certain northern line, drawn it would seem almost arbitrarily, is to be heard in lavish numbers in certain favored spots. The red-tail is here from Egypt and Abyssinia, and, as they have nests to build and eggs to lay on the shores of the White Sea, the chances are that in a few days more the shivering citizen of Archangel may be rejoiced by the sight of the more enterprising members of the flock. The water wagtails are twittering on the muddy shore of the water-course which so recently overflowed its banks, and by the end of April the

turtle-dove is cooing in the fir-wood, as if rejoiced at once more seeing its native land after the prolonged visit to Nubia and the Upper Nile. The corncrake (p. 87), which seems, with its skulking habits and ungainly appearance, little fitted for the long flights it is compelled to make twice in the twelve months, suddenly proclaims its presence from amid the early corn; and if lucky, the ornithologist may catch a glimpse of the gay hoopoe and the golden oriol, which have an exotic aspect, and are indeed only occasional visitors to these northern climes. The fly-catchers are rarely here before the second week of May, but long before that period the familiar swallow has assured us—the proverb notwithstanding—that summer is here at last. The sand-martin is the earliest of its kindred to come and the soonest to leave; and the swift is so apt to linger on its way, now hawking around a Kaffir kraal in South Africa, anon halting a little while in circles about the Moorish towers of the Alhambra, from the windows of which, in happier days, the languid ladies of the harem used to angle for them with artificial flies, so the spring is well advanced before it appears on the English downs. All summer these little feathered folk revel in the joy of existence. The pair build their nest, rear their young, and disappear, until the observer who was intent six months before in watching their arrival may find a sadder but not less intellectual amusement in noting how one by one they vanish from the woods, the commons, the fields, the gardens, and the river sides, where they had to all appearance established themselves for good.

By October some of them have left. Almost before the falling leaves enable us to fully realize that autumn has arrived, the fly-catchers, the warblers and pipits, vanish from their accustomed haunts. Before the stubbles are bare the white-throat is on its way to Malta, or Corfu, or Asia Minor, and the chiff-chaff, which was braving the east winds of March, takes care to be ready for a flight to Sicily before the September gales have ruffled her dainty plumage. The nightingale, it is a matter of almost general knowledge, is curiously limited in its range over England. In summer it flies as far westward as the Spanish Peninsula, and as far northward as Denmark, yet it is absent from Ireland, and its rumored visits to Scotland are not very generally credited; while, according to Mr. Harting, the boundary line over which it rarely trespasses takes in Cornwall, West Devon, part of Somerset, Gloucester, Hereford, the whole of Wales, part of Shropshire, the whole of Cheshire, Westmoreland, Cumberland, Durham, and Northumberland, though it has been doubted whether its range is much north of the town of York. Its western boundary seems, therefore, formed by the valley of the Exe, the occasions on which it has overstepped this limit being extremely rare, and in many cases its supposed occurrence in certain spots and at certain dates rests entirely on the *ipse dixits* of people who affirm that they "heard its song." The "early nightingale" of the newspaper paragraph is usually a song thrush. The bird rarely, if ever, makes its appearance in these islands before the fifteenth of April. What is more, it shuns Brittany and the Channel Islands, though so numerous are they in the valley of the Thames that bird-catchers will sometimes secure a couple of hundred after a few nights' work. Yet, though so abundant that as soon as the first glimpse of spring is on us the Philomel is chanting his "harmonious love" in every grove from Twickenham to Blackheath, and delighting late loungers on river-side lawns with his sweet concert, after the middle of June it is only in exceptionally mild localities that a single note can be heard from the songster, which, according to Fletcher and an absurd bit of folk-lore "singeth with 'her' breast against a thorn." At the first

approach of autumn, Philomela is off with other blithesome feathered friends to the Mediterranean, and is rejoicing the sad hearts of the invalids, who, like her, are trying to escape their native fogs in Tangier, Cairo, or Smyrna. The wheatear will before then have deserted the rabbit warren, and the whin-chats and stone-chats are no longer to be seen on the furzy common, where the linnet and the brambling have taken their places. Thrushes and meadow pipits, which had fled from the snows of their summer haunts by the Petchora and the North Cape, have usurped the strongholds of the white-throats and yellow wagtails, and the home of the tuneful willow-wrens by the bosky hedgerows and coverts are tenanted by noisy tits, reckless of the coming storms. Some few, indeed, seem as if uncertain whether to go or to remain. Pied wagtails and woodcocks may be found all through the winter, and other birds, like the song-thrush and the robin-redbreast, which are faithful to England in sunshine and in storm from January to December, are in many Continental countries regular migrants. The waxwing, the nut-cracker, and the Pallas sand-grouse, though not usually reaching our longitudes, are sometimes impelled to migrate by that longing for travel which seizes so many of their kindred. But the cuckoo, the nightingale, the swallow, the swift, and the martins, are pre-eminently our migratory birds. They are associated with spring and summer and autumn; and though the newspapers never fail to record the fact of a stray specimen having been shot in some remote quarter, one no more looks for a corncrake or a swift in February than for the sea-serpent or the sulphur shower when Parliament is fairly in session.

But marked though the migratory season is in England, we see less of it than do our Continental neighbors, especially those who inhabit countries on the line of the great spring and autumn flights to and from the north of Europe. Morning and evening, and, indeed, all day long, the Heligolander may watch from his red rock in the North Sea the wild ducks winging their way in long "badelynges," led by an elderly drake performing the part of a personal conductor, and quaking with joy at the sight of the river mouth which they had in memory ever since they left the Lapland lakes or the Siberian tûndra. Every night—unless the sky is clear and the moon enables the migrants to continue their flight without trepidation—there is a Babel-like clamor overhead, and the lighthouse lantern is surrounded by myriads of larks, snipes, and plover, which have beat against it on their dreary night journey from the north, or by the mysterious-mannered knots returning from their philanderings in some nameless land around the Pole. In one night sometimes as many as 15,000 larks have been caught, and though the resident birds of Heligoland do not exceed a dozen species, it is, perhaps, no exaggeration to say that the visitors exceed those of the greatest country in Europe.* But on a smaller scale the same spectacle may be witnessed in almost any spot similarly situated. For example, the keeper of the lighthouse at Atlantic City describes the migratory birds as following the New Jersey coast all the way up and down in their flights. At night they fly high, and when they see Absecan Inlet light, which is 167 feet above the ground, they head directly for it. They seem to be attracted in the same way that the moths which flicker around a candle are. If carried along by a heavy wind, they dart against the plate-glass windows surrounding the lens, and drop to the ground dead, bespattering

* Such a scene as that described is figured in Mr. Seebohm's "Siberia in Europe," p. 242; and from personal observations during an autumn residence on Heligoland, I can amply confirm the accuracy of this description, as well as of the earlier one by Mr. Cordeaux of a similar sight contained in his paper on Heligoland Ornithology (*Ibis*, 1875).

the panes with their blood, to prevent which a wire netting has been constructed on the north and south sides of the lantern. Not long ago a large duck, which was sailing along in a furious storm, was dashed against this netting with such force as to indent it six square inches. When the weather is clear immense numbers of small birds hover about the light after dark, and then as soon as they have rested on the rail surrounding it, fly off, but soon return again. A large snipe landed so violently against the wire-work that he plunged through one of the meshes, and stripped himself of all his feathers as far back as the shoulders.

In like manner the residents in the Frisian Islands, which form a breastwork to Continental Europe—and of which Heligoland is one—have fine opportunities of observing the practical outcome of this strange migratory instinct of birds. In September and October the church roofs of Sylt and Föhr and the Peninsula of Jutland are covered with vast flocks of thrushes and other migrants, drawing breath before resuming their southward flight; and on every church tower in Denmark, North Germany, and Holland, may be witnessed those solemn assemblages of storks which are held preparatory to the meditative birds taking wing for Tanganyika, Timbuctoo, or some other African watering-place.* The chimney swallow, which in October was twittering under the eaves of the manor-house in Kent, may possibly be recognizing the squire as he suns himself in the Algerine town which they have both chosen for their winter quarters, and the night-jar, which was in such a hurry to leave us that she had no time to build a nest, is, perhaps, a week after taking her departure from Surrey, comparing notes with its vocal rivals among those palmetto groves beyond which peep the minarets of the Great Mosque of Morocco. In July every Arctic cliff is moving with bird life; by October or November, at latest, the raven and the snowy owl are almost the only fowls left to give a semblance of the busy world to the snow wastes glittering under the cold moon and the weird-like northern lights.

This feverish desire to be off infects all those subject to it, no matter in what position they may be placed. Nearly every bird is, indeed, more or less migratory: that is, it changes its quarter to a certain extent according to the season of the year. Even cage birds, reared from the eggs of parents who never knew what freedom was, get as uneasy as a Londoner in August, and if their prison doors are left open, will sometimes desert their helpless young in order not to be too late for the winter hegira. The house martin has been known to do so repeatedly; and if the autumn is colder than usual, the swallow and the Carolina wax-wing will suddenly take their departure from Canada, leaving their callow brood to die of starvation, the instinct of self-preservation being evidently stronger than that of maternal affection. What is more—and there could be no better proof of the "migratory instinct," which the term indicates—the young of such birds brought up from the nest, and apart from their parents, display the yearning quite as conspicuously as do their own civilized brethren. Finally, as we have already hinted, the instinct is variable, for the same species often mi-

* Their nests may be frequently observed on the square towers or minarets of the mosques in Morocco. During our long ride from Fez to Tangier, in November, 1884, we noticed numbers arriving; and with such semi-pious respect do the Moors, Berbers, and Arabs treat "B'elharge," that not unfrequently the young ones might be seen perched on the backs of the sheep and cattle. They are emblematical of faith: to kill one would be sacrilege. These congregations of birds in council are, however, not confined to the stork. It is, indeed, common to find migrants so consulting over the journey to be taken. Many of my readers may remember the "Swallow Parliament" which meets on fine autumnal afternoons upon the dome and circular gallery of the Radcliffe Library, at Oxford.

grates in one country and is stationary in another, or, as Mr. Darwin points out, different individuals of the same species in the same country are migratory or stationary, and these can sometimes be distinguished from one another by slight differences. The quail, for example, is migratory in South Africa, but stationary in Robben Island, only two leagues from the continent, and in Ireland the quail has lately taken to remain in numbers to breed there. In Germany, in addition to robins, there are migratory and non-migratory thrushes, the one being distinguished from the other by the yellow tinge of the soles of their feet. In the Falkland Islands, on the other hand, no land bird is migratory, and there is no migratory bird in Mauritius or Bourbon.

Yet, large and ever increasing though the extension of bird migration is, the causes which lead to this curious trait are very imperfectly ascertained. There is, of course, much speculation and many specious theories intended to dovetail into some still broader hypothesis, but sound inferences from well-confirmed facts are much rarer than one might have hoped after the years of observation which have been lavished on this department of biology. We know all about the spring and summer flights of the migrants—and their routes are singularly determinate—but we are still as ignorant of the motives of these fixed northern and southern journeys as we were before Palmen, and Newton, and Grebel, and De Serres, and Cordeaux, and Harting, and Adams, and Seebohm, wrote so learnedly on the theme. Of one thing we are certain: migration is no new habit, either in birds, beasts, or fishes, for as long as history affords us any data to go upon there are references to this instinct; and palæontologists are now generally agreed that there are proofs of it having been practiced ages before man came upon the earth. The "hawk that stretches her wings to the south" is a bird as well known and inexplicable, as regards this portion of her manners, as she was when Job pondered over her ways. Every autumn the water-fowl throng to the rivers of Asia in the same mysterious fashion that they did when Homer wondered from whence they came. "Anacreon's Song Divine" celebrated the coming of the swallow, but he did not tell why she came any more than can the last Nile boat traveler or the gentleman who annually favors us with a dissertation on the subject. The Greek children still celebrate the coming of the swallow as did the little Rhodians two thousand years ago in the rhyme preserved for us by Theognis and Athenæus, of which one variant may be thus freely Englished:

> "She comes, she comes, who loves to bear
> soft sunny hours and seasons fair:
> The swallow hither comes to rest her
> sable wing and snowy breast,"

just as the Hungarian boys rejoice over the vernal appearance of the stork on the island of the Danube, or the Indian of the Fur Countries, in his rude calendar, names the "moons" after the birds of passage, whose arrival is coincident with these changes. But "who bids the stork, Columbus-like, explore heavens not his own, and worlds unknown begin? Who calls the council, states the certain day? Who forms the phalanx and who points the way?" are yet, as in Pope's day, questions to which we can return no certain answer, though year by year we are approaching nearer and nearer to the wished-for goal.

The individual swallow it is now ascertained, returns from the Canaries or North Africa to the very spot on which it built its little mud mansion the previous summer, and, according to the observations of the celebrated Jenner, marked birds were caught at their old nests every year for three successive seasons. This fact is so remarkable that, even after allowing that the swallow tribe are gifted with extraordinary powers of localization,

and that their summer homes are well defined, it is something wonderful to remember that a bird after seven months' absence can still have treasured up in its memory, through the varied fortunes and vicissitudes of two long journeys, the recollection of the landmarks necessary to guide it to and from its summer home. For many years in succession a pair of blue titmice built their nest in an earthenware bottle placed in the branches of a tree in a garden at Oxbridge, near Stockton-on-Tees, and even where the surface of the country has undergone a complete change, some species will continue breeding on the beloved spot. In America, orioles and vireos appear to return to the same tree, or even to affix their nest to the same branch, for many successive years; and in like manner, Allen has noticed how the wren, the pewee, and the robin, repeatedly occupy the same nesting sites. So mysterious did these facts—the sudden disappearance and equally unexpected appearance of birds—appear, that at one time it was believed that the nightingale, the cuckoo, and the corncrake hybernated, as do bats and bears. Even up to comparatively late times many naturalists of deserved eminence favored the absurd theory of swallows passing the winter in the mud at the bottom of ponds. We know better now, for as a famous zoologist remarked in regard to the coming and the going of the puffins, were they sea-fowl satellites revolving round the earth, their arrival could not be calculated with greater accuracy. Yet we are unwilling to leave the explanation among the somethings "in this earthly ball" which are to be "unriddled by-and-by."

In the first place, some of our old ideas regarding migration have been undergoing a considerable revolution. We have seen that migration in one form or another is a law of nature. Most birds and quadrupeds are more or less in the habit of changing their *quarters* according to the season of the year. Even the sparrow is migratory in some districts of the Continent, and in general terms it may be said that there are few, if any, birds of the northern hemisphere which do not in some degree practice this seasonable vagabondage.

Food, and the necessity for obtaining it, have been adduced as the principal causes of migration from north to south, or from east to west, and to a certain extent this is true. The birds which breed in the Arctic regions, and along the shores of Russia, Siberia, and the "barren lands" of North America, the snow buntings, the geese, the ducks, the turnstones, and a host of others, must necessarily seek milder latitudes if they are to live when the snow covers their feeding-grounds, while it is equally evident that insect-eating birds, like the swallow, cannot remain long in regions from which insect life disappears for several months in the year. But this explanation fails when we come to the vernal migration, for it can scarcely be supposed that the swallow or the fly-catcher would leave a region where there is perpetual summer, and winged food in superabundance, in order, after risking a long journey over land and sea, to find a greater scarcity of the same kind of proviant? It is equally improbable that the seed and fruit eaters who, since October, have been fattening amid the gardens of Algeria and Egypt should suddenly, in March or April, be possessed of such an inordinate craving for a change of diet as to fly three thousand miles on the chance of picking short commons in an English spring. Yet both here and in America the departure of the birds is regulated very strictly in accordance with the disappearance of the particular food on which they subsist. Thus—to take the United States—the swallows, swifts, and fly-catchers are, with a few exceptions, the first to leave and the latest to arrive. Those which subsist on insects, but also affect, in part, soft pulpy fruits—the vireos, tanagers, and grosbeaks, for

example—are almost as early in their departure and as late in their return as those which are exclusively insectivorous. In North America, we are assured by Mr. Allen, the great mass of the warblers and thrushes tarry still later, while the hardier seed-eating finches remain till the leaves have fallen and sharp frosts have seared the fields. The sandpiper, woodcock, and snipe linger till the oozy marshes and shores fail to yield their accustomed food, and the water-fowl abandon their summer haunts only when the cold hand of winter has locked up in ice the inland lakes and rivers, or driven their finny prey to deeper waters. "The non-migrating species"—I am quoting the eminent American naturalist already mentioned—"as some of the woodpeckers, the omnivorous crows and jays, and the grouse, are there when food is of such a nature that the change of season only remotely affects the supply. As would be naturally inferred, the distance traversed by the migrating kinds in passing from their summer to their winter homes is in direct relation to their habits in respect to food; those wholly, or almost wholly, insectivorous, being not only the first to leave, but those which penetrate farthest south, only finding congenial surroundings in sub-tropical or inter-tropical regions."

At the same time, it would be a mistake to infer that size in any way governs migration, though length of wing may. The smallest birds often fly much farther than the biggest. The Swedish bluethroat performs its maternal functions among the Lapps, and enjoy its winter holiday among the Negroes. The blackcap consorts all summer among douce Presbyterians in Scotland, and all winter is at home among pyramids and mosques in Egypt, and the gray wagtail, which was in October the guest of a Kentish vicar, is by November twittering itself a welcome from the Hadjis of Mecca and Medina. The ruby-throated humming-bird proceeds twice a year from Mexico to Newfoundland and back again, and the cuckoo, which is much slower on the wing, will fly with ease from Northern Europe to Africa or the Persian Gulf. The stork, which is, on the other hand, the largest of the migratory birds, leaving the marshes of Holland, or the pleasant land of Denmark, a few days later is seen in great flocks, making for some portion of Inner Africa. The capacity for taking such flights ceases to be a theme for wonder when we find that the common black swift is able to cover 276 miles an hour, a speed which, if maintained for about six hours, would transfer it from Surrey to the Soudan and the purple swift of North America is affirmed to be even more powerful on the wing. The chimney swallow is said to be able to attain a rapidity of flight averaging ninety miles an hour; the ordinary carrier pigeon has been known to fly from Paris to Bordeaux —distant in a straight line 300 miles —in seven hours, while we have the authority of a naturalist, who has so attentively studied the bird life of North America as the late Professor Leith Adams, for affirming that the passenger pigeon travels at the rate of about one thousand miles a day.

It is therefore clear that while food is one of the prime stimuli which impels the migrants to leave the north in autumn, we must seek for some other causes to explain why in spring they return from winter quarters, where every description of nutriment is so abundant to one where it exists only in small quantities. It has no doubt been advocated that birds leave their winter quarters because in southern climates the heat dries up everything and lessens the superfluity of insect life. This, unfortunately, is not the experience of the traveler, who is tortured by mosquitoes and all other winged pests, or of the farmer, whose crops are devoured by grasshoppers, or of the gardener, whose plants are preyed on by aphides and beetles, or of the

olive-grower, who is sometimes at his wits' end for a means of destroying the insect plagues which descend on him. In reality, in all tropical countries, there are endless varieties of insect-eating residents, and even in Greece, where several swallows winter, one variety is found there all the year round. It may also be added that in the north there is not always food for the second comers to the same district, and that in consequence the weaker are driven away by the stronger, a circumstance which aids in the gradual movement from north to south, and *vice versa*. In Düsseldorf flocks of swallows arrive early in April, circling over the town like a swarm of bees, but we are told by Mr. Seebohm that in May the swifts appear on the scene and soon become as abundant as the swallows were, while the latter birds are rarely seen during the summer. Food, therefore, though among birds, as among all created beings, the *primum mobile* of emigration, is also insufficient to explain the theme of this paper.

Temperature has unquestionably much to do with the vernal and autumnal shifting of quarters, though what is the exact connection between the arrival of the migrants and that of the weather we cannot say. An early winter or a late spring hastens or retards the emigration and immigration of birds, and hence, to a limited extent, geese, ducks, and similar arrivals from the north, deserve the popular esteem in which they are held as harbingers of severe weather, for cold comes from the north, and where it hardens the soil or freezes the water out of which these birds devour their food, they must necessarily leave earlier than they would otherwise have done. But, as Mr. Newton very justly remarks, they often arrive with the very weather they are held to prognosticate, while sometimes this does not follow their appearance. It is, however, too sweeping a conclusion to infer that birds have no ability to discern approaching storms. From a vast series of facts accumulated, especially in America, it is clear that the southward emigration of geese and other water fowls "usually precedes, often by only a few hours, the approach of heavy storms, and a sudden and very great reduction of temperature, which they often avoid by keeping in advance of the change." It is also well known that many birds display restlessness just before the occurrences of severe storms, and that some, which are not migratory in the usual sense of the term, move southward in large flights, as if preparing to avoid the tempests brewing in the north. Some birds are more hardy than others: the swallow is particularly tender. The tiny wren lives through the Scottish winter.

But after allowing that the migrants which come and go with such regularity can regulate their movements in an appreciable degree by the rise and fall of the mercury, it still remains to be explained why they leave the mild south for the inclement north. The hyperborean ranges which they claim for their summer residence are, perhaps, the best for their nesting functions; yet it puzzles us to understand how this fact has become so deeply impressed on the bird's brain that it experiences an irresistible desire to return after the lapse of a definite interval, unless, indeed, on the unavoidable conclusion that this is due to a blind instinct, or that the old birds have the power, as no doubt all the higher animals have, of communicating their experience to the younger members of their species.

And this leads us to consider how far the passion for *procreation* influences the migration of the feathered race. The breeding stations of birds are their true homes; their winter residences are only their halting-places during the "off season" of the year. But it is stretching a point to suppose that in returning to their birthplaces the migrants are influenced by that "nostalgia" which the wanderer displays when, forsaking

the lands of everlasting summer, he returns to the uninviting spot in the bleak land which is associated with his earliest recollections. A more reasonable hypothesis—though like many conclusions of a similar character one incapable of demonstration—is that birds, like other animals, have implanted in them an instinct which tells them that now is the season for mating, nest-building, and egg-laying. And, as if confirmatory of this speculation, it has been noted that the young, or immature birds of some species which require several years to attain maturity, pass the summer at points far to the southward of the usual southern limits of the breeding range, while in other cases there are laggards which, according to Mr. Allen, who has particulary noted it, arrive much later than the fully matured birds. Still, here as elsewhere, there are objections to the complete acceptance of a theory which is compelled to depend so much on the faculty of instinct, since there is more written than is understood about this mental manifestation. Here is one. The parental duties are supposed to hasten the spring departure, but there is nothing to justify us in asserting that birds show the least disposition to pair before they make each other's acquaintance in their summer haunts. The birds of the southern regions are as migratory as those of the northern. Many species visit New Zealand, Australia, and South America only during the breeding season, and though the tropical birds prefer for the most part to nest there, the chances are that, if we include in birds of the torrid zones those species which visit them "after having bred in the cooler regions, they will also contain a considerable proportion of migrants even though no bird migrates there to breed." "We might lay it down as a law," writes Mr. Seebohm, "that every bird breeds in the coldest regions of its migration." No bird migrates to the tropics to breed because there is no hotter region for it to migrate from; and he holds that "well-authenticated stories" of birds breeding a second time in the place of their winter migration is akin in scientific value to the tales of swallows having been found hybernating in caves or hollow trees, or of toads having been found in the recesses of otherwise solid rocks. And here it may be noted that, in addition to the two regular migratory waves—one north-east in spring and the other south-west in autumn—there is yet, quite independently of these, a continual stream of immigrants, week after week and month after month, to the eastern shores of these islands, coming directly across Europe from east to west, or more commonly from points south of east to north of west and the reverse in spring, These immigrants are mainly composed of well-known species which annually make these islands their winter quarters, and as a rule take the place of our summer birds. They come in one broad stream, but denser on some special lines or highways than others. "Cutting the line of ordinary migration at nearly right angles, one flock brushes the Orkney and Shetland Isles, passing through the Pentland Firth, even touching the distant Faroes. The southern wing crosses the Channel Islands, shaping its course in a northwesterly direction to the English coast." *

And now we come back to the place whence we set out. Granting that birds are impelled to migrate, by some irresistible instinct, when was the instinct first acquired, and if not innate from the beginning of time, what was the cause which first led it to be acquired as a factor in the struggle for existence, since it requires but a brief study of nature to see that every action of animal life is more or less dictated by the desire for self-preservation? At one time it was supposed that birds in flying from the north took no very determinate course, and

* "Report of the British Association Committee on the Migrations of Birds," 1883.

especially that in crossing the sea the line followed one year was not, unless accidentally, the same as that adopted in the next. We now know this to be a mistake, for Herr Palmen, a Swedish ornithologist, has with infinite industry and long observation determined that birds in their migration wing their way over the same route year after year, even though a different one might be shorter and therefore more convenient. These routes so far as the region studied goes, are as follows, and without pinning our faith to the exact details, it may be said that with a few exceptions nearly every naturalist is agreed as to the general facts.

The first route is that which, leaving the Siberian shores of the Polar Seas, Novaia Zemlia and the north of Russia, passes down to the west coast of Norway to the North Sea and the British Islands. The second proceeds from Spitzbergen and the adjoining islands, and follows much the same course, but it is prolonged past France, Spain, and Portugal, to the west coast of Africa. The third begins in Russia, threads the White Sea, and the Lakes of Onega and Ladoga, skirts the Gulf of Finland and the southern part of the Baltic, and to Holland, *viâ* Holstein, where it divides, one branch uniting with the second named route, while the other running up the Valley of the Rhine and crossing to that of the Rhone, splits up on reaching the Mediterranean, where one path passes down the western coast of Italy and Sicily; a second takes the line by Corsica and Sardinia, and a third follows the south coast of France and the eastern coast of Spain, all three paths ending in North Africa. The fourth route, as well as the fifth and sixth, all set out from the extreme north of Siberia, but after this take divergent courses. For instance, the fourth, ascending the river Obi, branches out near Tobolsk; one track diverging to the Volga, descends that river, and so passes to the Sea of Azof, the Black Sea, and thence by way of the Bosphorous and Ægean to Egypt. Another track makes for the Caspian, by way of the Ural River, and so leads to the Persian Gulf, while two more are lost sight of on the Steppes. The fifth mounts the Yenessei to Lake Baikal, and thence into the plains of Mongolia. The sixth ascends the Lena, and crossing the Upper Amur reaches the sea of Japan, where it combines with the seventh and eighth, which run from the eastern portion of Siberia and Kamschatka. The ninth leaves Greenland and Iceland, passes the Faroe Islands to Britain, and then joining the second and third routes run down the French coast.* It is the same in America, though, owing to the less settled character of much of the country, the routes have in the New World not been so accurately determined as in the Old. Seas such as the English Channel and the Mediterranean are no barriers to the migrants, though in crossing the latter they do so in three routes: by the South of Spain, near Gibraltar, by Sicily over Malta, and by Greece and Cyprus. Furthermore, on examining some of the other routes taken, it is found that they pass over the lines of shallowest water, pointing out where in former times a long since vanished land connection existed. At a comparatively recent period, the Mediterranean seems to have consisted of two lakes, Europe and Africa being connected by way of Spain and Italy. At this period in the world's history, Great Britain was evidently in union with the Continent, so that birds which now cross two seas on their annual migration might have acquired the habit at a time when no such sea existed. They traveled by these land bridges so long that when they gradually disappeared, the birds having acquired the habit, transmitted it as an instinct to their descendants, and continue to do so though the sea has for unnumbered ages rolled where prior to the Tertiary period, or perhaps well into that

* "Om Foglarnes flyttningsvägar" (1874), or Professor Newton's summary, which has been followed.

era, there were undulating plains. Mr. Wallace, who was the first to formulate this theory of the origin of migratory habits, has so concisely stated its leading principles that it may be well to quote his exact words. "It appears to be probable," writes this eminent biologist, speaking of the question under discussion, "that here, as in so many other cases, 'survival of the fittest' will be found to have had a powerful influence. Let us suppose that in any species of migratory bird breeding can, as a rule, be only safely accomplished in a given area; and further, that during a great part of the rest of the year sufficient food cannot be obtained in that area. It will follow that those birds which do not leave their breeding area at the proper season will suffer and ultimately become extinct; which will also be the fate of those which do not leave the feeding area at the proper time. Now, if we suppose that the two areas were (for some remote ancestor of the existing species) coincident, but by geological and climatic changes gradually diverged from each other, we can easily understand how the habit of incipient and partial migration at the proper seasons would at last become hereditary, and so fixed as to be what is called an instinct. It will probably be found, that every gradation still exists in various parts of the world, from a complete coincidence to a complete separation of the breeding and the subsistence areas, and when the natural history of a sufficient number of species is thoroughly worked out, we may find every link between species which never leave a restricted area in which they breed, and live there the whole year round, to those other cases in which the two areas are absolutely separated."

This explanation of the origin of the migratory instinct, and the reason why birds take certain determinate routes over the sea, is in perfect agreement with the conclusion at which Mr. Darwin arrived at an even earlier date, though the facts were not published until after his death. Instincts, he shows, can be acquired. Birds which were once perfectly fearless of man now display the usual terror, since the oceanic islands which they inhabit have been visited or settled, and transmit their prudent instinct to their offspring. On the other hand, while at first frightened by passing railway trains, they soon learn that these novelties betoken no danger, and so in time the birds alongside the lines view them with the most perfect equanimity. The sheep, which in Spain are taken every summer to pastures in another part of the country, acquire, by-and-by, an instinct for this artificial migration, which is displayed by curious uneasy motions, so strong that about the time when they ought to be off it requires all the vigilance of the shepherds to prevent them escaping, and there are cases in which the journey has been performed, the animals reaching their old feeding-grounds without assistance. Certain savages—the North American Indians and the Australians, for example—have this instinct in almost as great perfection, for it is usually said that they will find their way from one part of the country to another in a manner perfectly wonderful. I have reason to believe that the stories about their capacity in this respect are exaggerated; but it is not quite correct to affirm that this faculty only exists as regards their own part of the country, and that, therefore, it is simply experience, for they display it in almost as great perfection in any part of the region which they inhabit, though they were never there before; and Wrangel has noted with admiration how the Tuski of Siberia guided him through an intricate labyrinth of hummocks of ice with incessant changes of direction. Now, it is impossible to believe that they could have been acquainted with every spot on an ice-field which forms and is destroyed within twelve months. Yet, while Wrangle was watching the different turns, compass in hand, and trying to reason the true route, the natives had

a perfect knowledge of it instinctively. How far this is the case with birds, or how much of their power of guiding themselves over seas is due to experience and observation, we shall see presently. But that the migratory habit, as like other habits, becomes acquired until it becomes an instinct, there need be no doubt, and that the explanation of how this instinct was acquired may be accepted until the progress of knowledge renders both theories no longer tenable. "Take," remarked Mr. Darwin in the latest published of his writings, "the case of a bird being driven each year, by cold or want of food, slowly to travel southward, as is the case with some birds, and in time we may well believe that this compulsory traveling would become an instinctive action, as with the sheep in Spain. Now, during the long course of ages, let valleys become converted into estuaries and then into wider and wider arms of the sea, and still, I can well believe, that the impulse which leads the pinioned goose to scramble northward will lead our bird over the trackless waters, and that by the aid of the unknown power by which many animals (and savage men) can retain a true course, it would safely cross the sea now covering the submerged path of its ancient land journey."

That migratory birds know the position of the magnetic pole is a hypothesis too absurd to be worthy of a moment's discussion; and it is not much less difficult to understand that they guide themselves over broad oceans, and are able to find the nest in the hedgerow round which they twittered six months before, simply by the aid of a highly-developed instinct for locality. Yet this is the only hypothesis which we can accept, though how they can distinguish north and south is not quite so easy to comprehend. It must not, however, be supposed that the course of migratory birds is "unerring." They frequently lose themselves. Of the millions which begin the flight from the northern breeding-grounds, a comparatively small number reach the winter quarters. Tens of thousands are every autumn drowned, and when the night is dark they seem at a loss how to proceed, alighting in prodigious numbers on such spots as Heligoland. They may sometimes be seen hovering in great flocks over towns, uncertain what the blaze of light means, and, as we have seen, vast numbers are killed by flying against the lighthouses they encounter in their perilous journey. Migration is, indeed, so fraught with mortality to the migrants, that it has been suggested one of its chief purposes is to keep down the increase of bird life, which would otherwise be so enormous as to become a positive danger to the other inhabitants of the world. Dismissing this application of the doctrine of final causes as a little too far fetched; there cannot, nevertheless, be a doubt that migration is not accomplished without a great proportion of those that take part in it perishing before they have proceeded far on their journey.

Experience plays a part in piloting birds during their journey, which until recently was not fully recognized, the "mysterious unerring instinct" being a doctrine too alluring to be deposed in favor of any such everyday fact as this. Yet, even those who do not quite accept Herr Palmen's assertions about determinate routes, and go so far as to declare that in America, at all events, the spring and autumn ones are different, and that the comparative scarcity of birds by one route one year, and their abundance the next, indicates that the lines of migration vary, are ready to accept the idea that birds acquire and transmit their geographical knowledge of the journeys they make. They do not always fly straight to the goal, as would be the case were they guided in their course by an unerring instinct. They follow well-marked physical features, the windings of a river, a valley, or a coast line. That birds possess remarkable memories for direction and locality is proved by their being able

to find their carefully-concealed nests in reeds, marshes, thick hedgerows, dense forests, or grassy prairies, after flying away for a long distance to feed, and, as we have seen, swallows and birds of prey return year after year to the same nests, herons to the same swamps, and even the same trees, and many sea-fowls, like cormorants, terns, and gulls, to the same stretch of sandy beach, or rocky cliffs abandoning them only after a long course of ceaseless persecution from man. Birds which make their migrations over continents do so in a leisurely way. They tarry here and there, resting themselves, and studying the lay of the land. Their sight is we know, preternaturally keen, and they can, in consequence, fly with ease between landmarks which to our less perfect vision seem hopelessly far apart. Even birds which fly over seas are not without guiding lines. Those which make such journeys generally take islands like the West Indies on their route, and when they visit the Bermudas from the adjoining continent, as the roaming plovers and sandpipers do, they are able by their strength of wing to make the passage quickly, and may possibly find guidance in the sun, in the prevailing winds, or, as has been suggested, in the change of temperature attending change of latitude, even when their sharp eyes cannot, from an elevated position in the air, scan the lofty coast they are bound for.

So far good. Still, after all has been said, there remain many difficulties. Birds we know, are very easily deceived. The lark will soar on a January day provided the sun shines with a summery glare, and thrushes may sometimes be heard singing in December or January, provided the weather be mild. In the winter of 1883–4, a starling's nest with a young brood was found, though the same bird must have had another in August or September, the bird being unquestionably deceived by the spring-like climate of the early winter months. On the other hand, D'Orbigny declares that a lame hawk in South America knew the period of three weeks so accurately that it used, at this interval, to visit the monasteries where food was distributed to the poor. But memory, or even the most elementary experience, can have no part in the young cukoos' start for the first time, two months after their parents have departed. Again, if experience was the only guiding power of birds during long journeys, it would naturally follow that the old birds would accompany the young ones. But the very contrary is the case. The young and the old always travel separately, and the fledglings form the van of the southern migration. Mr. Gätke, Colonial Secretary of Heligoland, who has perhaps the best opportunity of any ornithologist for observing such facts, asserts that of the 360 species of migratory birds which he has himself taken on the island, in one case only did the old birds precede the young in the autumnal flight. In all others, the young got the start of their parents by some weeks, the old males, who so often lead the hegira, being the last to migrate. The one exception is the cuckoo, the old birds in this case winging their way south or north before the young, which they had left to be brought up by a stay-at-home foster mother. The contrary arrangement is observed during the vernal migration. In spring the first flocks consist principally of adult males. The second week's arrivals are composed mainly of adult females; in the third week follow the birds of the year; and finally, during the last week of the northward migration, come the cripples—birds which have lost their toes, or a whole foot, birds with half a tail, birds with one portion of the beak abnormally long, or birds with some other physical defects. In autumn there is also a visitation of the maimed and the halt to Heligoland, some weeks before the regular migration is due. These individuals Mr. Seebohm describes as in various stages of plumage—summer, or winter, or in the transition stage between

the two, and moulting as they go. These *avant-courriers* who loaf about for a few days in a desultory sort of way, are supposed to consist of barren birds, and birds who have been unable to find a mate, or birds whose nests have been destroyed too late in the season to allow of a second nest being made. "Having nothing else to do, the hereditary instinct to migrate not being checked by the parental instinct, they yield to its first impulses, and drift southwards before the general body of the species."

Here, therefore, is a difficulty which, on the theory of experience, is hard to get over. Experience, however, Mr. Wallace will have it, exerts a great influence over all animals. He will even hint that one bird learns how to build its nest from another, and that until some great garden is netted in, and then, various birds reared from eggs in confinement, turned out with enough of raw material to work with, we shall never be able to say how far the "instinct" for building their homes after a certain fashion is innate or merely a form of art quickly acquired from observation.

The subject is, therefore, not quite so easy as the glib formulation of mechanical theories would have us to suppose. Nor is it a simple matter to explain offhand, or to fit into any one of the popular systems of the day, the fact of certain birds in certain families staying at home and others which might seem equally well able to bear cold, and which subsist on the same kind of food, migrating with the utmost regularity. The birds which have the most northern range in summer have, it has been affirmed, the most southern range in winter also, and that this wide flight depends on the superior power of wing possessed by the individuals in question. It may, therefore, be possible that the fact of the old males preceding the migration in spring may be due to their greater strength, and that if the young birds are the advanced guard in autumn, this is only at first, the observer in places like Heligoland being too near the starting-point of the southern flight to judge whether this inequality in the speed of travel is permanent. Still these are the facts, and unless they are refuted by others equally strong, they form an insuperable barrier to the easy flow of the kind of "explanations" vouchsafed. In any case, if experience goes for much, that the young birds should be started off ahead of their parents is an eccentricity which we should not have expected.

These are the principal data known about the migration of birds, though so extensive has the literature of the subject become,* that a volume would not suffice to digest all that has been ascertained regarding this peculiar trait of the feathered tribes, not to mention the same habit in certain mammals and fishes. It will have been seen that it is surrounded with difficulties. So far as at present known—to sum up the results in a few words—it resulted from changes of climate occurring at a geological period dating from the close of the Pliocene epoch. It has been ascertained that there is every gradation of the habit, and that representatives of the same species may be sedentary or roving "according as they inhabit the northern or southern portion of the common habitat." Food and cold compel the birds to remove south, and the procreating instinct to shift their quarters to the north. It is believed that they pursue definite routes, though whether guided by inherited experience, instinct, memory, or eyesight, is still a problem which only the future can solve. Observations—always observations—are what is required, and so long as these are accurate, and recorded without refer-

* I have not thought proper to distract the reader's attention by detailed references to these authors. The principal have, however, been mentioned, and in addition to the information derived from them, the writer has availed himself of much personal observation in many parts of Europe, America, the Arctic regions, and North Africa.

ence to pre-conceived ideas, they will form welcome additions to our ever-accumulating pile of data.

SNOW.

By Geo. G. Chisholm, M.A., B.Sc., F.R.G.S.

Every one knows that snow consists of frozen drops of water, that it is in fact made up of minute particles of ice. Every one knows also that though made up of frozen drops of water, snow never falls in round globules like rain. The irregularity in the shape of a snowflake would probably, indeed, be one of the first points of distinction that would strike an ordinary observer in comparing it with a raindrop. Yet the truth is that snowflakes, though indeed different in form from raindrops, have a regularity of their own just as perfect and far more wonderful than that which characterizes unfrozen drops of water falling through the air.

This regularity, however, is usually concealed by the manner in which the snowflakes fall. In our islands snow falls as a rule when the weather is comparatively mild for winter, when the temperature of the lower air is near or even above the thawing point; and though the air is generally calm at the time it is seldom so absolutely still that the feathery flakes are not driven more or less out of their course in their fall. This being so, the different snowflakes are driven into contact with one another, and when the temperature is near the thawing-point, they then readily unite into one. Hence it happens that the snowflakes that fall to the ground in an ordinary snow-shower are not those originally formed in the higher regions of the atmosphere, but irregular little masses of such, which have been aggregated together by frequent collisions in the lower strata.

Sometimes, however, the air is so still during a snow-shower that the particles of ice fall to the ground just as they are formed, and this is especially apt to be the case when the temperature is so low that they do not readily unite even when they strike against each other. The beautiful and wonderful regularity that distinguishes the structure of the particles is then apparent at a glance. Each one of them is then seen to consist as a rule of a little star of six rays, exhibiting the most perfect symmetry. The rays are all of equal length and are all inclined to each other at the same angle. This angle must necessarily be one of 60°, since all the six angles formed by the meeting of the six rays make up the 360 degrees that form an entire circle, and each angle is therefore one-sixth part of 360 degrees.

But these stars are seldom made up of simple lines proceeding from a center. They are adorned in the most various ways, but however various the forms may be there is always the same symmetry in the adornments as in the ground plan. If one ray is adorned by feathery projections on each side, then all the other rays are adorned by precisely similar feathery projections; and in whatever way the rays are varied, they always correspond exactly with one another.

Such symmetrically-formed snowflakes are known as *snow-crystals.** These exhibit the most extraordinary variety. Scoresby, the Arctic navigator, enumerated ninety-six varieties of form belonging to five leading types, and since his day upward of a thousand forms have been described.

Notwithstanding all this variety it is curious that in the same snow-fall the flakes generally assume only one form and seldom more than three or four. Whether it be the temperature, or the relative quantity of moisture in the air at the time of the snowfall, or other conditions which determine the precise form which the snow-crystals assume, that form does seem to be due

* See illustrations in No. 2 Humboldt Library.—"Forms of Water."

example, that this regularity of structure is not confined to particles of water which freeze separately in the air, but also to water frozen in the mass, to what is called *ice* as distinguished from *snow*. To prove this was not easy. Pure ice is as colorless and transparent as glass. When we look through it we see no evidence of what is called structure. We see no arrangement of parts built together so as to form the mass; we see apparently nothing but a perfectly homogeneous body. Moreover, when we break ice it falls into *irregular* fragments, in which we can trace no signs of a regular structure any more than we can by looking through it.

Still *there is* a way of showing the regularity in the structure of ice, a very simple and ingenious method devised by Professor Tyndall. His plan is this: he takes a slab of ice and causes a ray of light to pass through it at right angles to the surface of freezing, and then fall on a white screen behind. Now this ray of light is accompanied by heat, and the heat serves partially to melt the ice through which it passes; but it does not melt a hole right through the ice: it melts a particle here and a particle there, and in doing so reveals the structure that was previously undiscernable. By melting a particle here and there the transparency of the ice is interrupted, and the screen now reveals a number of figures known as *ice-flowers*, each of which has a bright spot in the center, and, like a snow-crystal, has six rays, inclined to one another at precisely the same angle, and variously adorned with symmetrical outgrowths.

It is not merely in solidified water that this definite structure is displayed. Under favorable conditions all substances, all the elements and all their inorganic compounds, assume such a structure in passing into the solid state. The parts composing such solids are all called *crystals* from the Greek word for ice (*krystallos*), and the structure itself is called *crystalline*. Such a structure is often revealed by the fact that the substance breaks more readily along the faces of the crystals than in any other direction, and when such is the case the substance is said to have a *crystalline cleavage*. Frequently the crystalline form is obvious on the surface, and even where this is not the case there are other ways, besides that of cleavage, by which it may be detected.

It must not be supposed that all crystals are of the same type as those of snow and ice. The different types are indeed very numerous, but there are a few great facts which have been shown to hold good of all crystals, and to one or two of these it will be worth while to direct attention.

In the first place, all crystals have either three or four primary "axes" to which their form is related. To understand what is meant by the axes of crystals and how their form is related to them is important. The axes are imaginary lines intersecting one another in the middle point of the crystal, and so situated that by following them we can conceive the crystal as divided up into a number of similar parts—four when there are three axes, and six when there are four axes. Thus, if we take a crystal with three axes and imagine it to be divided into two by a plane passing from top to bottom along one axis, and from end to end along a second, then the third will be divided into halves; and if each half of the crystal be next divided into halves by planes passing through half of the third axis, then we shall have the crystal divided into four parts exactly equal in size and exactly similar in form. We thus see that the axes are lines with reference to which the parts of a crystal are symmetrically arranged.

Secondly, all crystals of the same kind, that is, formed by solidification of the same substance *under the same conditions* have the relative values of the axes constant. If the axes are all equal in length in one crystal, then they are all equal in length in all the others; if one is longer than the other two or three, then in all the rest the

corresponding axis is longer than the others in just the same proportion. But under this limitation there may be many modifications in the form of the same kind of crystals, and as to size there seems to be no limit whatever. Crystals of the same kind may be so small that they cannot be seen without the aid of a microscope, and so large as to weigh between 200 and 300 lbs.

The same substance may, however, crystallize in one form in one set of circumstances, and in a form of a totally different type under other conditions. Several of the elements do so. Carbon, for example, crystallizes in one form as the diamond, in another as graphite. Sulphur likewise has two crystalline forms, and so also have phosphorus, silicon, and some others. But more commonly it is found that one substance always crystallizes in one form, and very often different substances crystallize in the same form. When this happens it is frequently possible to get two such substances to crystallize together into one lump, the separate crystals easily fitting into one another; and, what is still more curious and interesting, it is sometimes found that two substances forming crystals of nearly though not quite the same form will crystallize together, the crystals then being intermediate in form between those proper to the substances crystallizing separately. The crystals have thus a certain power of *mutual accommodation*, in spite of the exactness with which they habitually maintain their own form.

Such are some of the general facts that have been found to hold good regarding crystallization. The explanation of these facts, as we have said, is still to seek. But though science has not yet succeeded in offering a complete explanation of the forms of crystals, it is yet able to point to an analogy which may guide us in looking for one.

Tyndall lays great stress on the analogy of the magnet. He asks us to observe that the power of the magnet is concentrated in its two extremities and is wholly wanting at the middle. Either end will attract iron filings, one end will attract and the other repel the north end of a suspended magnet, while the middle point has no action in either case. Divide your magnet into two, however, and then you find that you have two magnets which behave precisely in the same way as the undivided magnet did. What formed the middle or inactive portion of the large magnet is now as active as the two extremities, and the inactive portions are now situated midway between the ends of the two halves of the original bar. The same thing holds true, however minutely the magnet be divided, and physicists consider themselves entitled, and indeed, bound, to infer that no limit would be reached till we got to the molecules, or ultimate particles, of which the magnet is composed. It is in these molecules, they believe, that the magnetic force must be found in the last resort; and these molecules therefore must have antagonistic properties at their two ends. Minute as they are, so as to be beyond the range of the most powerful microscope, and not capable of being discerned by any of our senses, we must still conceive of them as having a certain length, and as having each a north end and a south end, with the properties characteristic of a magnet a foot in length. As the force displayed by them is exercised at two ends or poles, they are said to be bi-polar, and it is by the mutual action of the innumerable molecules contained in it that a large bi-polar magnet is formed.

Now we may imagine that crystals are similarly built up of molecules with definitely localized powers of attraction and repulsion, and that it is to this fact that they owe their definiteness of form. That such is the case can, indeed, hardly be doubted; but what there is in the molecules of a magnet, or of freezing water, to give them polarity of one kind or another is still unknown, and may forever remain so.

These beautiful forms of the snow "crystals" have led us far, and we must not forget that there are other things worthy of attention to be observed in snow. First of all we will notice what no one can fail to have observed, the extreme lightness of this substance. We are all familiar with the way in which the flakes, in falling, are driven about by the slightest breath of air, and every one knows, likewise, that a handful of snow is perhaps as light a handful as one can lift. The actual weight of snow depends very much upon circumstances. Snow varies greatly in compactness, but on an average it is found that a cubic yard of this substance weighs about 187 lbs., or about one-twelfth of an equal bulk of water. Ice itself is lighter than water, but in nothing like the same proportion; and a certain volume of snow would, on an average, have only about one-eleventh of the weight of an equal volume of ice. No one will be at a loss to understand the reason for it; it is so manifest that snow in the mass consists of innumerable little spicules of ice interlaced together, and having a great quantity of air enclosed in the meshes, that the lightness of this substance when compared with ice or water will not excite any surprise.

But there are other consequences of this composition that are not so obvious, and which are a good deal more interesting. How many are aware that it is to this circumstance snow owes the *whiteness* for which it is proverbial? Why is any substance white? So far as any answer can be given to the last question it is the answer involved in the Newtonian theory of light. According to that theory pure white light is seen in the rainbow or the solar spectrum, and the color which any object assumes to our eyes depends on the way in which that object deals with the compound light. Some of the rays may be absorbed by the object and others may be reflected from its surface or pass through it. All may be absorbed and all may pass through. In the latter case the object is perfectly transparent, and when only some of the rays pass through, as, for example, only the red ones, then the object appears to us to be of the color of those rays. In any case an object assumes to our eyes the color of the rays which reach our eyes from it, whether these rays be reflected from its surface or transmitted through the object. Now as sunlight is white, when all the rays composing it are reflected from any surface, the sensation of whiteness must be produced in us; and, conversely, when we see a white object, we must conclude that it reflects all the sun's rays. We must believe this, therefore, of snow just as of chalk or milk.

But in the case of snow something more has to be said. If we carefully examine any individual flake of snow, we see that the minute spicules of which it is composed are not a solid white but, *transparent*. Instead of reflecting all the sunlight that falls upon them, they allow nearly all the light to pass *through*. If that is true of the individual spicules, why should snow in the mass, even in very small masses appear white? The answer to this question is furnished by another fact in optics. It is found that where light passes through substances of different density, even though these substances be each perfectly transparent, that is, capable of allowing the rays of all the different colors to pass through, yet some of the light is always reflected where the surfaces meet. The rays so reflected do not belong to any particular color, but to all the colors composing the light. In other words it is a portion of the white light that is reflected. Now in passing through snow light is constantly changing from a medium of the density of ice to one of the density of air. At each surface of each spicule of ice composing the snow, a portion of the light is reflected, and the whole of the light is thus reflected before it makes its way very far through. Hence it happens that snow, though composed of transparent parti-

cles, is itself perfectly white, and at the same time absolutely opaque.

And snow is by no means the only object whose whiteness may be so explained. The explanation applies to all similar cases. A sheet of glass is as transparent as a slab of ice ; but pound the glass into fragments, and you get a white opaque powder. Each of the little particles in that powder is still transparent, but the heap is not so. So, too, pure water is transparent, but when water is lashed into foam the foam is white and opaque. The foam is composed of thin films of water enclosing minute bubbles of air, and the light that falls on it must pass as far as it can alternately through air and water. It is just the same when water appears in the form of steam. Steam consists of minute globules of water dispersed through the air, and hence there is again the same alteration of media of different densities for the light to pass through. How white steam may be we all know from seeing it escape from the funnels of steam-engines, and how opaque it is we may perceive by considering the depth of the shadow which it casts on the ground on a bright day. It was one of Faraday's experiments to show on a screen the shadow cast by a jet of steam emitted in the path of a powerful beam of electric light, an experiment which he employed to illustrate the opacity of clouds of vapor, and the difficulty (and indeed the impossibility) of furnishing lighthouses with lights strong enough to shine far through dense fogs.

Let us now consider another consequence of the composition of snow. It is to the fact of its being made up of an interlacing mass of spicules with air enclosed in the meshes, that snow owes the property which gives it perhaps its chief value in the economy of nature. The property referred to is that of protecting the ground which it covers from the winter's cold. There are few who are unaware that snow does fulfil this function, but *perhaps* few, also, who realize the extent to which it does so. Were it not for the snow that regularly covers the ground to a great depth during the winter months in the Arctic regions, the hardy plants that flourish there would perish, hardy as they are. Pretty severe cold they must indeed be able to stand, but not the cold of the polar atmosphere, which is very much greater than under the snow. At Rensellaer Bay, in lat. 78½° N. it was found on one occasion that while the air was at a temperature of 30° below zero Fahr., the temperature at a depth of two feet was only 8° below zero, at a depth of four feet 2° above zero, and at a depth of eight feet 26°, or only six degrees below the freezing point of water.

The animals of the same regions partly owe their power of standing the winter to the same protective covering. Under the snow the lemming passes the winter, feeding on the stems of willows, and what other food it can find ; under the snow the Arctic fox pursues the lemming; under the snow the female polar bear sleeps through the winter in a natural cell which goes on enlarging through the warmth of its breath.

But perhaps the most striking illustration of the protection which a covering of snow affords against cold is furnished by the way in which it was at last found possible to naturalize in gardens on the Continent of Europe some of the peculiarly beautiful and brilliantly colored plants of the Alpine regions, which it had often been attempted to naturalize in vain. During the winter they always died, till an ingenious gardener hit upon the device of affording them artificially the protection against cold which in their native seats they regularly obtain from their covering of snow. He did so by putting them in the greenhouses along with the orange and pomegranate trees of warmer climates, and his experiment was crowned with success.

The fact, then, that snow does afford a very efficient protection against cold is beyond question. But

how does it do so? If there were a continuous covering of ice instead of snow the ground underneath would soon lose its heat and be reduced to the temperature of the air above, for ice is a sufficiently good conductor of heat. If there were no covering at all, the ground would lose its heat even sooner. But the air entangled in the meshes of the icy particles that form snow, renders the mass so bad a conductor of heat that the ground is able to preserve its temperature in the manner we have seen. It is just in the same way that furs and feathers keep the body warm. It is the air entangled among the hairs of the fur, and the barbs and barbules of feathers, that makes such coverings so bad as conductors of heat that the animals clothed by them are enabled to a large extent to defy the winter's cold. The difference between the average weight of snow and that of water, as given above, will enable the reader to conceive how much air there must be enclosed as a rule within snow, and the amount is specially great in the snow that first falls in the Arctic regions. It is for that reason that, to use the words of Kane, the Arctic navigator, "no eider-down in the cradle of an infant is tucked in more kindly than the sleeping dress of winter about the feeble plant-life of the Arctic zone."

The protection which snow affords against cold is perhaps the most important function that it fulfils in the economy of nature, but it is not its only function, nor its only important function. In mountainous regions it accumulates moisture that might otherwise have fallen in repeated torrents tearing the soil from the mountain sides, inundating the valleys, and spending almost all its energy in destruction, and allows that moisture to be stored up for future use, to feed the streams that water the valleys and to keep them filled with comparative regularity and constancy. In level countries it performs a similar service in another way, keeping the underlying ground refreshed with water that trickles from the snow as it is slowly melted from underneath by the warmth of the earth itself.

In level countries especially, snow renders another important service to man in facilitating travel and the transport of goods. In this country we are not likely to think of snow from this point of view, for with us it is rather dreaded as an interruption to traffic, through blocking up our railway cuttings as it often does in the north. In the steppes of Russia, on the other hand, the snow season, before the introduction of railways, used to be awaited in order to allow of the easy carriage of goods from inland towns to the ports of the Black Sea and the Baltic, and even since the introduction of railways the snow there adds greatly to the facilities for transport. In Northern Europe the Laplanders make long journeys in winter in their sledges drawn by reindeer; in Greenland and North America the Eskimo use in the same way their sledges drawn by dogs; in Canada the snow brings on the sleighing season, and thus affords the population the most keenly relished of the pleasures of winter.

Snow is not always our friend. We have just called attention to one mode in which it may be injurious instead of helpful, namely, through the interruption of traffic. That, however, is not the worst of the evils which it sometimes works. In thinly-inhabited countries there is no greater danger than to be overtaken by a heavy fall of snow or caught in storms of snow-dust, raised from ground on which snow has previously fallen, and whirled along by the wind. In such cases one's only safety is to make at once for the nearest human dwelling in sight. If there is none in sight the danger of being lost is great, for nothing so destroys one's sense of direction as the confused eddies of falling snow or swirling snow-dust.

In mountainous countries snow is attended by another danger. It ac-

cumulates on the mountain sides and may lie there till it gradually melts or evaporates; but it may fall in large masses carrying destruction along with them. Such sudden falls of masses of snow, snowslips as they might be called, are known as *avalanches*, and are of two kinds. In German Switzerland these are all called respectively *Staublawinen* or dust avalanches, and *Rutschlawinen* or sliding avalanches. It is difficult to say which is the more terrible when they occur in places where living beings or anything constructed by human hands may be in their path.

The former, the dust avalanches, occur in winter when the snow is powdery and little coherent. Successive falls of snow may have heaped up such accumulations that they are only just able to rest upon the slopes which bear them up. If anything does happen to destroy the equilibrium of any portion of the snow, sometimes, it is said, if there is only so much commotion of the air as is caused by a shout, or even by persons speaking in the neighborhood, that portion slips down, and, disturbing the snow beneath, displaces it also. The avalanche thus gathers volume and impetus as it advances, and if not soon checked by meeting some obstacle which it cannot overcome, may attain such a size as to be able to overwhelm an entire village, while the violence of the wind set in motion by its onrush causes the loose snow all round to be whirled aloft in dense clouds, and is sometimes sufficient to uproot trees on both sides of its path. One case is recorded in which the wind-gust of an avalanche overturned sheds on the opposite side of a river to that on which the avalanche occurred; and on another occasion the spire of the convent of Dissentis, in the Grisons, is said to have been thrown down by the gust of an avalanche which fell a quarter of a mile off.

The other kind of avalanche, the Rutschlawine or gliding avalanche, called in French the *avalanche du fond*, is apt to take place in spring or summer when the snow is melting. It generally occurs at the head of a valley when the water running from the melting snow has, so to speak, lubricated the slope on which the snow rests. The snow then begins to slide down the valley in a compact mass, increasing like the dust avalanche, in volume and rapidity of movement as it advances, but always remaining compact and firmly coherent. Though an avalanche of this kind never sweeps over so large an extent of ground as a dust avalanche may, the shock with which it strikes is necessarily greater. But probably the greatest danger attending this kind of avalanche lies in its tendency to block up the beds of streams and cause wide-spread inundations.

The best defense against avalanches is found in forests growing on the mountain sides in such positions as to check their career before they are fully formed. Forests so situated are placed in Switzerland, and other parts where avalanches are liable to occur, under the protection of the State, and the heedless destruction of such forests has in certain cases led to the depopulation of considerable districts.

We may mention yet another way in which snow may act destructively. This is by giving rise to what are known as *ice-storms* in forests. When snow falls in forests, and especially in forests of coniferous trees, such as are most abundant in those regions where snow falls most plentifully, the branches of these evergreens become laden with a heavy weight of snow, which they may bear until the snow has been converted by partial melting and subsequent re-freezing into solid lumps of ice. These present a still greater surface for the reception of fresh snow, which may be converted into ice in its turn. Sometimes these accumulations attain such a weight that the branches can no longer support them. The topmost, weakest branches give way and

fall down with the lumps of ice that they carry. These, acquiring impetus as they fall, strike against the lower branches and break them off. Thus the process of destruction is accelerated. The agitation is communicated to the contiguous trees, and from these to others, and thus in a brief space of time large areas in a forest may be in great part destroyed.

Snow is not to be seen in all parts of the world. Most people have heard of the Eastern monarch who refused to believe in the possibility of the existence of water in a solid form. Experience had not enabled him even to conceive such a thing. And there are many parts of the world where one might have to travel very far before obtaining ocular evidence of the way in which water might be converted from a liquid to a solid, and from a solid again into a liquid.

Snow is indeed to be found in all latitudes, for all latitudes contain mountains high enough to receive coverings of snow. But at sea-level snow never falls within a certain distance of the equator. This distance is greater in the southern hemisphere than in the northern, for in the former the predeminance of water preserves a more equable temperature in the comparatively small areas of land. In that hemisphere snow is said never to fall at sea-level at a lower latitude than 48° S., while in the northern hemisphere the limit of snow at sea-level falls in some places as low as 30° N. This limit includes the whole of Europe, but in the extreme south of that continent, snow though it does fall at times at sea-level, does so very rarely indeed. The average number of snowy days in the year increases from the south northwards and from the west eastwards. At Rome, in lat. 41° 54′ N., lon. 12° 29′ E., the average is a day and a half, in the year, at St. Petersburg, in lat. 59° 56′ N., lon. 30° 19′ E., 171 days.

But in all latitudes snow may be seen at all times of the year wherever there are mountains sufficiently high. In all such mountains there is a line on which snow is always to be seen on the part of the slopes immediately above and generally reaching to the mountain top. This line is called the *limit of perpetual snow*, or more shortly the *snow-line*, and varies in height with the latitude, the exposure, and the average amount of the snow-fall, as well as with other transitory conditions, such as the temperature of a succession of seasons.

The term "perpetual snow" should not lead any one to suppose that there is any elevation at which snow, after falling remains absolutely unchanged. All the snow that falls on the mountains, however high, is destined to disappear in course of time. It may gradually be forced down by the weight of new accumulations to levels at which it melts and runs away as water; it may be blown down to lower and warmer levels, and in this way great quantities of snow are removed by every high wind on snow-clad mountains; it may be melted by the heat of the sun far above the snow-line, or it may evaporate or disappear insensibly in the form of invisible vapor. We are apt to think of the process of evaporation as one that goes on only when there is considerable heat, because it is most rapid and perceptible at high temperatures. But it is in reality a process that may go on even at freezing temperatures, and the rate at which it does so depends not only on the temperature but also on the dryness of the air. Now on very high mountains and in high latitudes the air is often very dry, and hence it sometimes happens that, even when the temperature does not admit of the melting of the snow, the amount present may be diminished with wonderful rapidity by evaporation. In such circumstances the toundras of plains of Northern Russia and Siberia have been known to be divested of snow in certain parts while the winter still prevailed. Still more striking proofs of the possibility of evaporation during the prevalence of freezing tem-

peratures are furnished by Hayes, the Arctic navigator, author of "The Open Polar Sea." He records that clothes, after being washed, were hung up wet in the open air in the coldest weather. Naturally they at once froze into stiff lumps, but in a few days they were found to be quite dry and soft. Similarly he observed that slabs of ice, in spite of severe cold, gradually shrank in size, and ultimately disappeared.

It is not, then, because the snow that falls on the tops of mountains remains always the same that there is a limit of perpetual snow on the highest mountains even in the tropics. But this limit is that at which snow never altogether disappears before fresh snow has fallen to take its place. It is for that reason that it is not temperature alone that determines the height of the snow-line.

That temperature is a very important factor in determining the height of that line is obvious, and hence it follows that as a rule the snow-line is higher the nearer the mountains are to the equator. On the south side of Mont Blanc, in the Alps, the limit of perpetual snow is about 9,000 feet above sea-level, while on the Andes, near the equator, it is situated at about the height of 16,000 feet—higher than the highest summit of the Alps. For the same reason the snow-line is usually higher on the side of a mountain exposed to the sun than on the side turned away from it. It is, for example, about 1,000 feet higher on the south than on the north side of the Alps.

But to this last rule it has long been known that there is a very important exception in the case of the Himalayas, an exception that proves that there is another important factor, besides temperature, affecting the height of the snow-line. Since the time of Humboldt attention has frequently been drawn to the fact that in those mountains the snow-line is higher on the north or colder side than on the southern, and therefore *warmer* slopes. The amount of the difference has been variously estimated by various observers, but there appears to be no doubt of the fact that the relative difference is as stated, not the reverse.

And it is not difficult to understand why it should be so. The southern slopes, though the warmer, are exposed to the moisture-laden monsoons which blow from the south during half the year in India, and at a certain elevation this moisture is precipitated in the form of snow. The northern slopes, on the other hand, are swept only by the comparatively dry winds that have crossed the interior of Asia, and hence the accumulations of snow in the course of the year are immensely greater on the south side than on the north. On the former side the power of the sun, on the Himalayas, just as on the Alps is greater in causing the snow to disappear, but as there is much more snow on that side to be removed in the intervals between the deposition of fresh snow, the line up to which its total disappearance can be effected is lower there than on the north.

The influence of the same cause in affecting the height of the snow-line is observable also in other cases. Before leaving Central Asia, we may note that on the Karakorum mountains, the next range to the north of the Western Himalayas, the snow-line is higher than on the corresponding slopes of the latter mountains, though as we pass still further north, to the Kuen-lun, Thian-Shan, and Altai ranges, in succession, we find that the snow-line descends the nearer we approach the poles, in accordance with the general rule.

Turning now to South America, we there meet with another striking illustration of the connection between the height of the snow-line and the amount of moisture in the atmosphere. On the southern parts of the Andes, Darwin was at first greatly astonished at observing the immense difference in the height of the snow-line within a comparatively small interval of latitude. In Central Chili, in about lat.

33° S., he found the snow-line at from 14,500 to 15,000 feet above sea-level, while only 9° further south, behind the island of Chiloe, he found it to descend to about 6,000 feet. But the explanation of this phenomenon, which he describes as "truly wonderful," he finds in the contrasting states of the atmosphere where this difference is observed. "The land from the southward of Chiloe to near Concepcion (lat. 37°), is hidden by one dense forest dripping with moisture . . . In Central Chili, on the other hand, a little northward of Concepcion, the sky is generally clear, rain does not fall for the seven summer months . . . No doubt the plane of perpetual snow undergoes the above remarkable flexure of 9,000 feet, unparalleled in other parts of the world, not far from the latitude of Concepcion, where the land ceases to be covered with forest-trees; for trees in South America indicate a rainy climate, and rain, a clouded sky, and little heat in summer."—Darwin's "Journal of Researches."

The last words of the passage just quoted remind us that, even where temperature is the principal factor in determining the height of the snow-line, it is not the mean temperature of the whole year, but the temperature of the summer months, and indeed above all that of the hottest month of the year. For when the summer is sufficiently hot it will melt away all the snow, however great the accumulations may be. It is in this way that the difference in the height of the snow-line in Iceland between lat. 60° and 62° N., and in Norway between the same degrees of latitude is to be explained. The mean temperature of the year for the two places is about the same, but in Iceland the temperature is more equable, while in Norway there is a colder winter and a warmer summer. The result is that the cold summer of Iceland allows the limit of perpetual snow to descend to about 3,000 feet while in the corresponding latitude of Norway it falls no lower than 5,500 feet. Hence, too, we find that the vicinity of the sea, while tending to produce a more equable climate, tends also to lower the snow-line on the mountains, so that, for example, that limit on the Pyrenees is about 2,500 feet lower than in the Caucasus, and upwards of 3,000 feet lower than on the northern slopes of the Thian Shan mountains, though all these ranges lie in nearly the same latitudes.

But seeing that there are so many varying factors affecting the height of the snow-line, it need not excite surprise that even on the same slopes that line is a varying one. The limit of *perpetual* snow, even with the explanation above given of the term, is strictly speaking a false designation. During one summer the line up to which the snow melts may be found to lie at one elevation, while if the next summer is much hotter, or if a comparatively snowless winter has intervened, the snow will melt to a higher elevation, and that will be the upper limit of snow for that year. That is one reason why the limits assigned for perpetual snow by different observers vary so much, though in many cases the observers affect to fix it with great precision.

To determine a really permanent limit of snow it would be necessary to take a long series of years, and to ascertain the highest elevation to which it has melted throughout the whole period. And even then it would be only a relative permanence that was ascertained, for in rare cases it is found that the cap may disappear altogether even from very high mountains. Thus Darwin was assured that during one long and dry summer all the snow vanished from Aconcagua, a peak of the Andes that attains the height of more than 22,000 feet. The snow is said to have frequently disappeared from the Pyrenees. From the Jungfrau, one of the highest summits of the Alps, it all disappeared in 1842; from the Strahlhorn, in the same range, in 1860–62; and from Chaberton in 1859.

We may conclude our consideration

of the subject of snow with a few words on the forms of life attached to this unlikely *habitat*. We do not here refer to the larger forms frequenting snowy regions, such as the polar bear and others already spoken of, but to the minute forms of vegetable and animal life found on the surface of snow. The best known and by far the most abundant of these is what is familiarly known as "red snow," a microscopic plant consisting of a single cell, which, when present, occurs in such inconceivably large numbers as to give a color to the snow over which it is spread. It has been found in the Arctic regions of Europe and America, on the high Alps, the Pyrenees, and the Carpathians, and was seen also by Darwin on the Chilian Andes. It was known even to Aristotle, who probably saw it on the mountains of Macedonia, but it was not till comparatively recent times that its true nature was discovered. By men of science it has had various names conferred upon it. Most commonly it is known as *Protococcus nivalis*, but more recently this name has been changed for that of *Sphærella nivalis*. Besides this red snow a green snow has been observed in Spitzbergen, also due to the presence of a minute vegetable form, and as many as thirty-seven species have been enumerated as belonging to the flora of the Arctic snows, and this flora is accompanied by a faunā equally minute.

CAVES.

BY JAMES DALLAS, F.L.S.

THERE is something connected with the name of a cave which calls up all sorts of strange and weird associations in the mind. This is, perhaps, in part due to our unfamiliarity with caves of any size, for though in certain parts of England they are sufficiently plentiful, yet it does not fall to the lot of every one to visit a cave district; and the vastness, the gloom, and the grotesque surroundings which we are apt to attribute to these natural excavations are, therefore, the result, not of experience, but of imagination. And the imagination is doubtless unwittingly influenced by the tales and stories of our youth, in which all kinds of impossible horrors, and of equally impossible charms, are connected in some mysterious manner with vast subterranean chambers, pregnant with palpable darkness or glittering with gems, and brilliantly illuminated, we know not how. We picture to ourselves the horrors of the den, which to the youthful imagination naturally becomes a vast gloomy cavern, whence the giant Slaygood sallies forth to waylay Bunyan's much-harassed Christian; or we invest with all sorts of magic beauties the wonderful underground apartments to which we are introduced in the fascinating pages of the "Arabian Nights." Most of us probably have hazy reminiscences of wonderful smuggler's caves and desert island caverns, the scenes of endless improbable adventures and of hairbreadth escapes, while the gloomy sea-shore refuge of Sir Walter Scott's famous smuggler, Dirk Hatteraick is as well-known to us as are our most familiar surroundings.

Nor is it only in works of fiction that allusions to caves and caverns are to be found. When King David fled in fear from Achish, King of Gath, he took up his abode in the cave of Adullam, where he was joined by four hundred followers, and it was in a cave at Engedi that he secreted himself when pursued by Saul. The five kings of the Amorites, after their defeat by Joshua, took refuge in a cave at Makkedah, whence they were brought out by the Israelites and hanged upon five trees, after which their bodies were re-consigned to the cave, and the entrance was blocked with stones, thus affording a historic instance of cavern-sepulture concerning which more will be said hereafter.

In ancient Greek and Roman

mythology, too, are to be found constant references to caves and underground habitations. If there was any idea at all of the nature of Hades, it was probably regarded as a huge subterranean vault or abyss, while many of the mythical gods, sibyls, and nymphs of the Romans were supposed to have their abodes in the interior of the earth, in caverns amongst the rocks or mountains. The Greek worship of Bacchus, Pan, Pluto, and the Moon, as well as the delivery of oracles at Delphi, were conducted within caves in the earth, while in Persia some connection seems to have existed between caves or caverns and the ancient worship of Mithras, the "Light-God" of the Arian races.

If by the ancients it was believed that supernatural beings were associated with the mysterious and awe-inspiring depths of subterranean caverns, their successors were certainly in no way behind them in attributing to these inexplicable excavations a similar unearthly association. In France and Germany the terms fairy, dragons' and devils' caves sufficiently denote the origin attributed to them in mediæval times; and until very recently, if not even in some places to the present day, caverns have been regarded by the rude and superstitious peasantry as the dwellings of evil spirits, fairies, and "Brownies," whose mischievous or benignant interference in the affairs of men forms so prominent a feature in the quaint nursery stories of Teutonic lands. One such story or legend is quoted by Mr. Boyd Dawkins, as having still been current as late as the middle of the last century, near Elbingrode, in the Hartz district. When preparations were being made for a wedding breakfast (so runs the legend), the friends of the bride and bridegroom proceeded to the neighboring caves, and demanded from the dwarfs who were supposed to inhabit them, copper and brass kettles, pewter dishes and plates, and other kitchen utensils. "Then they retired a little, and when they came back, found everything they desired set ready for them at the mouth of the cave. When the wedding was over, they returned what they had borrowed, and, in token of gratitude, offered some meat to their benefactors." Nor are stories of fairies and dwarfs, remnants probably of ancient pagan beliefs, the only ones attaching to caverns in the earth. Amongst the peasants of the hills of Granada it is still related, and perhaps half believed, that Boabdil, the last Moorish King of Granada, who was dethroned by Ferdinand and Isabella in 1492, now lies concealed in the caves of the mountains, and will, upon the entry of some rash mortal, be awakened from his torpor, and with his sleeping army revive in Spain the long extinct supremacy of the Moors

More authentic accounts of the use of caves as places of refuge are not wanting. Cæsar has related how the Aquitani, hard pressed by the well-trained legions of Rome, fled to the caverns of Auvergne, where they hoped to conceal themselves from the dreaded enemy; while quite recently, in 1845, five hundred Arabs betook themselves to a cave at Khartain, in Algiers, and, refusing to surrender themselves to the French, were suffocated by smoke, produced by the ignition of a mass of brushwood and other inflammable material at the mouth of the cave—an act of barbarity which has generally been attributed to the orders of Marshal Pelissier, afterwards governor of Algiers.

Interesting, however, as are many of the facts and legends connected with caves in almost all parts of the world, it is not to these that we wish specially to refer, for in fact still more interest attaches to the physical and zoological aspects of the subject, and to the light which is thus indirectly thrown upon the customs and affinities of the early races of mankind.

We are, perhaps, generally disposed to associate the formation of caves with the action of the waves upon a rocky shore, and certainly

some of the most remarkable caves are due to this cause. The process of attrition can indeed often be observed in actual progress, and those who have seen the gigantic waves break upon a rock-bound coast, and have observed the huge masses of stone, which have been torn away like so many fragments of timber and strewn upon the beach, can form some tolerably accurate idea of the power of the sea to eat its way into the face of any cliff, when once it has found a weak place in the rock. In the beautifully columnar basalt cliffs of the west of Scotland such a cave has been hollowed out by the fury of the Atlantic storms, and we are all familiar with the name at least of Staffa. Off the coast of Ireland is a similar and equally familiar cavern known as Fingal's Cave, which is also due to the action of the waves. These sea-worn caves are easily distinguished from those formed by other agencies. They are seldom of great extent, and they generally lie in a tolerably horizontal plane. Sometimes they lie far above the present water line, but the nearly level floor, the indication in their vicinity of an ancient beach, and the fact that in many cases at least similar caves of greater or less extent are to be observed opening on the same general horizon, prove conclusively that they must be due to the prolonged beating of the ocean waves upon a rocky shore. From the nature of their origin, it follows that these caves can seldom have been used as places of refuge or habitation either by man or beast; for even when the water no longer fills them at high tide or during violent storms, they are generally placed in positions almost impossible of access. It is not, therefore, strange that they present few marks of special interest to the naturalist, the anthropologist, or the geologist, though, indeed, their existence above the present level of the sea affords valuable and conclusive evidence of a rise in level of the land surface in their vicinity.

Caves are occasionally due to volcanic action, being sometimes produced by the expansion of steam and gases within a mass of molten lava, while in other cases they have been formed by the passage of lava streams over the surface of snow and ice, the subsequent melting of which of course leaves a hollow space or cavern. The cracks produced by violent earthquakes have also sometimes originated caves of greater or less extent, but the caverns which have the greatest charm for the student of science are those which have been eaten out of the solid rock by the gradual and imperceptible action of fresh water.

Perhaps the most familiar examples of caves thus produced are the hollows and excavations so frequently to be seen at the bases of inland cliffs. These are sometimes the result merely of atmospheric influences—frost, rain, and sunshine. Should the beds at the foot of a cliff chance to be of a softer material than the overlying rocks, they would naturally "weather" away more rapidly; but often the process of attrition is aided by a stream of water running at the base of the cliff, when hard and compact rocks would be readily worn away. The stupendous effects of prolonged weather action alone are, however, remarkably exemplified in the rock-shelters of the cliffs of New Mexico, Colorado, and the adjacent territory in the United States, where the mysterious cliff-dwellers made their abode.

Besides these surface caves there occur, however, others of greater dimensions, which penetrate into the very heart of the rock. When such caves are found in pure sand-stone rocks, they are the result solely of mechanical action. The rain water, falling upon the surface, gradually finds its way between the cracks or joints in the solid rock, and in passing through, slowly wears away a cavity, which increases in size with varying rapidity, according to the nature of the stone it traverses. Sometimes the trickling water meets with a

bed of softer and less compact material than the rest, and then true caves, and not mere vertical fissures, are the result. Such caves are of not unfrequent occurrence in the hard quartzose sandstones known as Millstone grit, which occur beneath the coal measures in Derbyshire and Yorkshire, as well as in other coal basins of this country. An excellent and well-known example is the cavern known as Kinderscout in Yorkshire, and similar excavations occur in sandstone rocks in many parts of the world. In the Tertiary sandstones near Paris, these water-worn caves have been discovered, containing the bones of extinct animals; and in Australia, though the explorations which have hitherto been undertaken have been of the most imperfect kind, the remains of animals have also been obtained from sandstone caves, while some most remarkable paintings, of very uncertain origin, have been observed in some of them.

But the interest attaching to these caverns or excavations dwindles into insignificance when we come to examine the vast subterranean vaults to be met with in the calcareous or limestone rocks. The great extent, the gloom and grandeur, and the beauty of these natural caves can hardly be exaggerated in even the most glowing descriptions, and it is scarcely to be wondered that all kinds of superstitious fancies should have been connected with them by the uneducated peoples of Europe and Asia. None but the boldest or most reckless of men would formerly enter their dark and chilly precincts, and they were consequently supposed to be more vast in extent than is even the case. Yet these extraordinary excavations were due not to any dread supernatural power, nor to any great convulsions of nature, but were the result of the gradual disintegration and wearing away of the solid rock by the mechanical action of running water, combined with the even more active influence of chemical decomposition.

The limestone rocks in which these vast caverns occur are to be met with in all parts of the earth, and owe their origin, for the most part, to the accumulation of organic remains on the bed of a no longer existing ocean. The shells of mollusks, and of those minute gelatinous creatures to which the name of Foraminifera has been applied, are, doubtless the chief, if not the only source of this enormous mass of carbonate of lime, and indeed some rocks, such as chalk, are almost entirely composed of the minute and beautifully formed calcareous shells of Foraminifera.

It was at no very distant date pretty generally believed that caves were due to internal contortions of the crust of the earth, by which the rocks were rent asunder, leaving gaps and breaks such as we now see. But an examination of the interior of the caves soon showed that this was quite an impossible explanation, for it was found that both the floor and the roof were composed of solid rock, and that so far from there being any indication of folding and crumbling of the mass, which could account for the existence of a cavity, the rock was in fact unbroken both above and below, and in most cases the lie of the beds was perfectly continuous. Then, again, it was supposed that the caves had been worn by the mechanical action of running water alone, in places where a fault occurred in the rock—that is, where from a local displacement of the beds, one portion of the series was elevated above or depressed below its normal level, thus leaving a vertical or diagonal crack, which might well be supposed to be a line of weakness. Probable as this view appears, it was, however, found that the caves did not in fact follow these lines, but were sometimes seen actually to be excavated across them, and yet another theory was necessary to elucidate their origin.

It has of course been observed by every one familiar with sedimentary rock quarries of whatever kind, that the stone displays not alone parallel lines indicating the successive layr

or beds of stratification, but also a series of irregular, and more or less broken lines, running in a direction to some extent vertical to the planes of stratification. These lines or cracks, without which it is difficult to conceive how quarrying operations would be possible, are technically known as joints, and it was found that water-worn rock fissures were in general to be traced to these cracks. The rain water falling upon the surface of the earth would of course naturally flow into any hollows, however shallow, which happened to exist upon the general surface of the rock; and when it chanced that a "joint" or fissure occurred within the area of the hollow, the water would gradually find its way downwards. The power of running water alone in wearing away solid rock is well known, but the water thus finding its way from the surface would also bear with it minute grains of sand, and these would aid in the attrition of the limestone over the exposed faces of which they were carried along. Neither water nor sand, however, of themselves would be sufficient to account for all the phenomena of cave formation; and, indeed it may be affirmed that alone they would be quite inadequate to produce the extraordinary results observable in some caverns. We must, then, seek some other and even more powerful, agent to account for the existence of such gigantic excavations as the Victoria Caves in Yorkshire, and the still vaster caverns of Kentucky and other regions of America. This agent is carbonic acid.

A large quantity of free carbonic acid exists in our atmosphere. It is given off from the lungs of every living creature, and in far larger quantities it is generated by the decomposition of animal and vegetable matter. In forest tracts, such as we may suppose all the cave regions to have been at the time when the formation of caves was in most active operation, the land must have been constantly strewn with leaves, branches, and other vegetable refuse in a perpetual state of decay, and hence there would be a large accumulation of carbonic acid in and above the surface soil. While thus floating about in a perfectly free condition, it would of course possess little power to act the part of nature's quarryman; but it happens that water has the power of gathering up into its volume a large quantity of carbonic acid, and thus the rain falling through the atmosphere and percolating the loose surface soil would gradually accumulate a large amount of this free acid, and bear it whithersoever it went. The principal ingredient of the ordinary limestone rocks is pure carbonate of lime, and this is quite insoluble in ordinary water. But any fluid containing carbonic acid has immense power in dissolving this substance; and even if it could not be proved, we might with great certainty affirm that the carbonic acid contained in rain water must be an important factor in the decomposition of limestones, and the consequent formation of caves. Fortunately, however, facts, which are ever more acceptable than theory, are not wanting to support this assertion.

There is to be found in the Doveholes in Derbyshire a small cavity, where in the line of a joint, the carbonic acid has attacked the limestone, and gradually eaten it away in fantastic patterns such as could not possibly have been produced by running water alone. From the sides of the main channel of the excavation are to be seen irregular honeycombed hollows, running upwards, downwards, and, in fact, at every angle from the line of the joint, which are to be attributed solely to the chemical action of the carbonic acid upon the carbonate of lime. The surfaces are worn into sharp points and angles, such as we see on a small scale when a piece of sugar is gradually dissolved by water, while minute fossils, formed of a harder and less soluble material,

are left standing out in bold relief when the softer limestone about them is eaten away.

Often the surface of a limestone country also affords striking evidence of the action of carbonic acid on the solid rock. In Yorkshire, the result of this action is most strikingly exhibited near Ingleborough, where the rain water, attacking the exposed limestone in the lines of joint, has gradually eaten away the solid rock, so that the whole surface is covered with chasms of varying depth. As the joints, for the most part, cross one another at right angles, the masses of stone standing above these chasms are approximately rectangular in form, and stand in a position of complete isolation from each other, while in some cases the effect of the acid contained in the water has been such that they are also detached from the underlying rock, and thus become transformed into "rocking stones." It is from facts such as these that geologists have been enabled to arrive at a satisfactory conclusion as to the mode of formation of caves in limestone rocks; but there is yet another piece of evidence, which should not be passed over, to be found in the enormous quantity of carbonate of lime borne in solution by running streams, which have during a part of their course passed through limestone rocks. Mr. Prestwich has estimated that the mean discharge of the Thames at Kingston is 1,250,000,000 gallons, and that each gallon contains on an average about nineteen grains of salts held in solution, so that in every twenty four hours no less than 3,364,286 pounds, or 1,500 tons, of mineral matter is carried down the river, and of this no less than about 1,000 tons consists of carbonate of lime. This gives us an idea of the power of rain water in dissolving limestone rocks, but the amount of carbonate of lime absorbed by the water which slowly percolates through cracks and fissures, coming in its progress into contact with no other material than limestone, must far exceed this quantity.

Great as is the part taken by carbonic acid in the excavation of caverns, there are yet other agencies which deserve a passing notice. It has been observed in the caves of Kentucky that certain beds of an argillaceous character, impregnated with earths and alkalies, are disposed to produce salts, and that these, oozing through the pores of the stone, effloresce on the surface, and thus take their share in the disintegration of the rock, and facilitate the work of the acid-laden water. Beyond this Mr. Dale Owen has remarked upon the tendency which some calcareous rocks have to produce nitrate of lime, to which cause he attributes not a little of the disintegration which occurs in limestones.

It has often been remarked that two other phenomena almost invariably accompany the existence of caves in a limestone country—"pot-holes and ravines." When a special origin was attributed to the caves, such as the contortions of the earth's crust already alluded to, or the subterranean effects of hydrothermal springs, which was a theory suggested by an eminent French geologist to account for the existence of caves, and to which cause undoubtedly some subterranean excavations, such as those which occur in districts containing a large amount of rock salt, are due, the intimate connection between these and the caverns was not of course recognized. But when the enormous power of acid-laden water in eroding and wearing away limestone was once admitted, it was easy to see that many of the surface peculiarities must be attributed to the same agency. The pot-holes which occur in all cave districts are funnel-shaped cavities, to which the varied names of "cirques," "betoires," "chaldrons du diable," "marmites de géants," "sinks," and "swallow-holes," have been applied.

Streams, and even rivers, may often

be observed to flow for many miles on the surface, and then suddenly to plunge down into the depths of the earth, the swallow-holes, or as they are sometimes termed, "swallet-holes," being the point of disappearance. But at other times the pot-holes seem to have been the original "reservoirs" in which the rainfall was collected prior to its disappearance between the underground cracks and joints in the rocks. Originally merely shallow basins or hollows upon the surface, they have been gradually enlarged by the combined chemical and mechanical action of the water, until they reach the vast proportions of the vertical shaft, about a hundred feet in length, known as the Helln Pot, near Selside, in Ribblesdale. It is to such beginnings as this that the limestone caves immediately owe their origin. The water which thus finds its way into the interior must gain an exit somewhere, though a geologist in former times hazarded the opinion that the stream of water thus penetrating into the interior of the earth served to extinguish the fires which were supposed to exist at its center. Often, as we know, these underground streams travel several hundred feet vertically, and sometimes many miles in a more or less horizontal direction; but though occasionally they enter the sea direct, they generally seem to find their way again to the surface, having gradually eaten and worn their way through the solid rock.

Year after year and century after century the unintermittent action of the stream goes on, until at length vast excavations are made in the depths of the earth, and the floors of the subterranean caverns form the beds of flowing rivers, which presently emerging to the light of day wind their course through the open country. Here, then, we obtain evidence of the intimate connection which exists between caves, ravines, and valleys. The stream emerging *from* the more or less perpendicular face of the rock not only increases the passage through which it flows by its own power of erosion, but it also forms a point of weakness, and affords an additional place of vantage to the various climatic influences which play their part in the process of subaërial denudation. Thus there is ever a tendency on the part of the overlying strata to break away from their attachments, so that fragments of stone, larger or smaller according to circumstances, are constantly falling from the roof of the mouth of the cavern, ultimately leading to the demolition of the face of the exposed rock. Hence, as time goes on, the entrance to the subterranean chasm gradually recedes from its original position, until eventually it may even reach the initial pot-hole, when nothing will remain to indicate the former existence of a cavern but a deep ravine, which will often be seen opening out into a less rugged valley. So impressed with this view was an eminent French geologist, M. Desnoyers, that he has termed ravines "*cavernes à ciel ouvert*," and Mr. Boyd Dawkins has suggested that the celebrated gorge of the Avon near Bristol owes its origin to the gradual breaking away of the roof of an immense cave or series of caves.

From the manner in which caves are formed, it will be seen that a vast period of time must have elapsed since the first tiny stream commenced to eat its way into the solid rock. The period, indeed, is so vast that it is impossible to fix it by any chronological data, and we have to look to the more extended epochs of geology in order to arrive at even an approximate idea of their age. The presence of "Rhætic" fossils in one or two of the English caves has led to the belief that these existed prior to the deposition of those immense masses of secondary rocks, including the Lias, Oolite, and Chalk, as well as all the more recent Tertiary and post-Tertiary beds. Whether or not such was in fact the case, it is impossible to say; but at least we may conclude

that most of the caves containing fossils must have originated at a much later date. Mr. Geikie has remarked that though very likely all caves of Miocene age may have been cleared away by denudation before the Pliocene period, yet it would be extraordinary had a similar fate befallen Pliocene caves before the immediately ensuing Pleistocene period, and he accounts for the absence of Pliocene fossils by supposing them to have been swept away by streams of running water. Attempts have been made by various observers to fix the approximate age of caves by a calculation of the rate of deposition of the carbonate of lime held in solution by the water passing through them. But before proceeding further, it may be better to glance at the manner in which this substance is deposited.

As the presence of carbonate of lime in the water is due to the excess of carbonic acid it contains, the evaporation of the acid must lead to the re-crystallization of the lime, and though so long as the water continues to traverse the cavern in any considerable volume, the evaporation, and consequent crystallization, is slight; yet any lessening of the velocity of the stream or volume of water at once leads to the deposition of large masses of pure crystalline carbonate of lime. In the still and shallow pools it shoots over the surface like "plates of ice, or is deposited in loose botryoidal masses at their sides and on their bottoms," while as water from the surface is constantly percolating through the roof, the walls of the caves become encrusted with masses of lime of the most varied and fantastic forms. Nothing can be more beautiful than the appearance of some of these stalactite caves, nor is it possible to convey any adequate idea of the multiform shapes which the pendent stalactites assume. Whatever their form, these stalactites are all due to one and the same cause—the never-ceasing drip of the lime-charged water from the roof. Grain by grain the lime is deposited, until the roof of the cave is covered with a drapery of white and glistening points, sometimes small and tapering, at others of great length or thickness. At one place may be seen a huge mass, like an inverted cone, extending from the ceiling half way to the floor, while below it is another immense cone, which has been formed by the water falling drop by drop from the stalactite above.

These stalactites sometimes attain gigantic proportions. In the Luray Cave, in Page County, Virginia, an immense mass which has fallen from the roof, and to which the inappropriate name of the fallen column has been given by the visitors, is over fifty feet in length and fourteen feet in diameter at the thicker end. Its estimated weight is no less than 400 tons, while some of the stalactites still suspended from the roof of the same chamber are said to be upwards of 500 tons in weight, and present the appearance of a "great inverted forest of blasted trunks." The Luray Cavern presents us indeed with a great variety of the grotesque forms produced by the crystallization of the trickling carbonate of lime. One chamber has received the name of the Fish-Market, in consequence of the strange growth of hundreds of flat sheet-like stalactites, arranged in rows like so many fish for sale, and an ingenious observer has even affirmed that there is no difficulty in identifying the species of bass, chad, perch, and mackerel, the illusion being completed by the trickling of water sufficient to give a slimy or fishy appearance to the objects. Perhaps no other cave in the world is more richly ornamented with stalactitic and stalagmitic decorations than that of Luray. The chambers are immense, measuring sometimes about 200 feet in length and 50 feet in height, and are draped or festooned with graceful folds and fringes so thin that the light of a candle reveals the entire structure within, or with the massive bosses already referred to. In the "Giant's Hall," for instance, is an apparently

interminable row of prodigious glittering columns, which "rise from out the depths of shade, and are lost in the overhanging gloom," while in the so-called Cathedral is a stone organ formed of thin sheets of stalactite of various lengths, which upon being struck give out soft musical tones, so that, according to a statement in the Smithsonian Report for 1880, familiar airs can be played upon them as upon a harmonicon.

Now and again, in place of these large stalactites we find congregated together an infinite number of tiny hollow stems, about the thickness of straws, through which the water from above still continues to flow. Strange as they appear, there can be no hesitation in deciding their origin. "They were formed," says Mr. Boyd Dawkins, "by the evaporation of the carbonic acid from the surface of each drop of water as it accumulated in one spot, and the consequent deposit of carbonate of limearound its circumference." Though little can be said with certainty as to the time required for the formation of these masses, some attempts have been made to arrive at an approximate estimate by the measurement of stalagmitic bosses in the English caves.

Sometimes the formation of an inch or two of stalactite has occupied many years; while, on the other hand, a layer of stalagmite nearly half an inch in thickness was formed in the cave at Ingleborough in a single year. A very interesting instance of the rate of formation of stalagmite is afforded by an inscription left by one enterprising and ambitious visitor to Kent's Cavern nearly two centuries ago. He left his name, "Robert Hedges, of Ireland, February, 20th, 1688," engraved upon a boss of stalagmite on the floor of the cave, and the rudely-cut letters are now covered by a film of carbonate of lime about one-twentieth of an inch in thickness. At this rate it has been calculated that the upper layer of stalagmite in Kent's Cavern, measuring about five *feet in thickness*, must have occupied 240,000 years; and the lower layer, measuring twelve feet, 576,000 years for their deposition; while the lowest estimates of geologists are 5,000 and 12,000 years respectively. Mr. Geikie has supposed that were the rainfall quadrupled the deposition of carbonate of lime would be largely increased; but we must not forget, in allowing for differences of this kind, that with an increase in the quantity of water passing through the cavern evaporation would probably be less, and that, therefore, there might be no very material increase in the rate of growth, except at particular points, and under peculiar conditions.

It is, then, clear that any estimate of the age of caves deduced from the rate of deposition of stalagmite cannot be regarded as satisfactory, and we are, therefore, forced to form our opinion of their age, to a great extent, from their contents, which consist partly of fossil bones and partly also of the remains of man's handiwork.

In a large number of the caves which have been examined, probably in all which have been excavated in limestone rocks, the interior presents similar characters. The lime held in solution by the water trickling through the roof of the cave not only forms stalactites, but also incrusts the walls of the cavern, and gradually finds its way to the floor. As it passes over this, a deposit of carbonate of lime is gradually formed, layer upon layer, and of great hardness. This coating of carbonate of lime, which varies much in thickness, is known as the stalagmite crust. Beneath this is generally found a yellowish or reddish fatty earth, composed, for the most part, of clay mixed with sand, in which are sometimes to be seen rounded and water-worn pebbles.

The presence of this red earth, which is equally familiar to geologists in this country and abroad, is evidence of the fact that these caves have not for a vast period of time been submerged beneath the waters of the sea, or of an inland lake; for it

is due to the slow and gradual accumulation of the insoluble material which has been left as a residue when the limestone was gradually dissolved away by the action of the rain water. How slow the accumulation of this deposit must have been will at once be recognized when it is considered how small is the quantity of foreign matter usually contained in limestone rocks, though perhaps a certain proportion may have been derived from the surface; but the difference between the silt thus carried into the caves and the true limestone refuse may frequently, if not always, be detected on careful examination. Sometimes this cave earth is loose and somewhat loamy in texture, while at others it is completely cemented together by the infiltration of carbonate of lime, when it forms a solid mass of great coherency, and can only be broken up with a pickaxe or chisel.

The extremely interesting remains of extinct and other animals which have been obtained from the limestone caves of this country and the Continent have been found almost exclusively in this red earth, or, as it is frequently termed, ossiferous clay. It must not, however, be supposed that their preservation is in any way due to the properties of the earth containing them, for in fact, where the bones remained dry, and there was no protecting covering of stalagmite, they were found to be in a completely decomposed state, and crumbled to dust the moment they were disturbed. When the stalagmitic crust is present, however, it forms a perfect hermetical covering, and beneath it the bones have often been found not alone perfect in shape and uninjured by time, but actually retaining something of their organic substance.

The interest attaching to the cave remains is very great, as they throw an unexpected light upon the early history of man, and also reveal to us a condition of things with reference to climate and physical geography, which, until these discoveries, we could never have suspected. During what has been termed the "Pliocene" period by geologists, we find, by the organic remains contained in the various strata of this age, that the climate of England and of Europe was much higher than it is at present, and this higher temperature continued into the succeeding "Pleistocene" age, to be gradually followed by a period of arctic cold, so that the caves of Europe have witnessed strange vicissitudes of climate, and the animal remains which they contain prove how great have been the zoological changes within the era of their formation.

The existence of fossil remains of animals in the caves of Europe has long been known. In the sixteenth and seventeenth centuries they were, under the name of "*ebur fossile*," or unicorn's horn, greatly esteemed as a medicine, and were obtained in great quantity from the caves of the Hartz district, and of Hungary and Franconia. Baumann's Hole in the Hartz had already become famous at the close of the seventeenth century, and descriptions of other caves and of their contents followed at intervals, until at last a new branch of investigation sprang up, the importance of which can hardly be exaggerated, when its bearings upon the early history of man are considered. It was long, however, before the possibility of man's existence contemporaneously with the extinct animals found in some of the oldest caves was entertained by the majority of scientific men; but the doubt was finally set at rest in 1858 upon the discovery of undoubted human relics in the celebrated Brixham Cave in Devonshire.

As cave exploration was carried on, and evidence of one kind and another accumulated, it was found that the fossil remains contained in them indicated at least two distinct zoological eras, in the later of which the animals belonged almost exclusively to species which still inhabit Europe, while in the earlier were found the remains of a number of animals, which not only are no longer to be found in this region, but many of which do not

even exist in any part of the world, and of such importance has this change in the fauna been considered that the Pleistocene period has been regarded as almost equivalent in geological value to the Pliocene or the Miocene periods, or at least to be separated by as definite a line from the more recent period as are the three previous eras from one another.

One of the earliest caves examined with scientific accuracy was that of Gailenreuth in Franconia, which was described by Dr. Buckland in his celebrated "Reliquiæ Diluvianæ" in 1824. Beneath the stalagmite floor were found immense quantities of animal remains, including the bones and teeth of the lion, hyena, cave bear, grizzly bear, mammoth, Irish elk, and reindeer, all of which have long ceased to exist in that region, and some, such as the mammoth and the cave bear, are quite extinct. Having learnt in the caves of Germany what was to be learnt of cave exploration, Dr. Buckland returned to England, and undertook the investigation of the caves of this country. As from them is to be gathered as much concerning the past history of the animal life of Europe as is to be obtained by a more extended search, we may confine ourselves to a brief examination of the contents of some of the English caves.

From the nature of the remains contained in the caves of earliest geological date, we are justified in believing that a high temperature must at one time have prevailed over the whole of Europe. Yet the evidence upon this point is somewhat contradictory, for in some of the earliest caves have been found the bones of the musk-sheep and of the mammoth, both of which doubtlessly flourished best in a cold climate; while, on the other hand, the presence in the caves of Kirkdale, Wookey, Uphill, and Cheddar, of such animals as the hyena, the panther, lion, hippopotamus, rhinoceros, and elephant, all of which are at the present time creatures of essentially tropical habits, leave little room for doubt that the climate was considerably higher in former times than now. The presence of animals of more temperate climes associated with these tropical forms has, therefore, been accounted for—by no means satisfactorily, however—by supposing that temporary changes of climate enabled first one and then another group of animals to frequent the same haunts and pastures.

It has often been matter of speculation and wonder how the numerous remains which are met with in caves came to occupy their present position. Sometimes undoubtedly they have been washed in by the agency of running water; but in many cases there is no doubt whatever that the caves were the lairs or dens of beasts of prey which lived upon the wild animals roaming the primeval forests of Britain, and that the bones which we now find are the records of unnumbered feasts. The proof of this fact is to be found in the condition of many of the bones, which have obviously been gnawed and eaten by wild beasts, and while all the softer parts have disappeared, only the hardest and most solid now remain. Doubtless the animals by which these remains were left were the spotted hyenas, which appear to have existed in considerable numbers in the Pleistocene age. No other creature perhaps possesses jaws so powerful, or teeth so capable of consuming solid bone. A comparison has been instituted between the bones left by hyenas kept in confinement and those which are found in the "hyena caves" and the similarity between them leaves no room for doubt that the fragmentary character of many of the cave remains is due to this cause. The soft portions of the extremities of the leg bones of oxen or bisons are found completely demolished, while the shaft is generally broken in such a manner as to admit of the extraction of the marrow. The head of the rhinocerous has sometimes been found in caves, but generally all that

remains is the small solid nasal bone upon which the front horn was supported. Other carnivorous animals, however, doubtless played their part in bequeathing to us these fragmentary remains of extinct creatures. Amongst them were the lion, the panther, and another feline to which the name of *Felis Caffer* has been given. There also existed a large bear, known as the cave bear (*Ursus spelæus*) which seems to have closely resembled the grizzly bear of North America; while in early Pleistocene times at least, existed a huge animal, known as the *Machairodus*, or sabre-toothed tiger, which possessed a masticating apparatus more formidable than that of any existing beast of prey, and which is known chiefly by the immense sabre-shaped canine teeth, with serrated edges, which are occasionally met with in the cave-earth.

Vast as is the lapse of time since the hippopotamus, rhinoceros, and lion roamed the country in a wild state, and since the spotted hyena preyed upon such creatures as he was able to kill or to find dead, there is not wanting evidence to prove that man, even at that early period, had found a place upon the earth. In the celebrated cave at Wookey Hole in the Mendip Hills, which, from the quantity of half-consumed bones it contained must for ages have been a favorite resort of hyenas, indications of the presence of man were found which admitted of no doubt. These consisted of an oval implement of flint, very roughly fashioned, a short arrow-head, and some fragments of chipped flint, together with two bone arrow-heads of very primitive workmanship, yet obviously the result of man's handiwork.

In caves containing remains of a later date, we find that all traces of the formidable Carnivora, and of the huge Pachyderms have disappeared, while the influences of man's presence greatly increase in importance. It is clear that the early inhabitants of Europe and of Britain must have dwelt commonly in caves when they were no longer infested with hyenas, and the relics of Neolithic men are numerous and interesting. We see amongst the animal remains the bones of the dog, pig, horse, ox, and goat, all of which were doubtless domesticated; while the wolf, the fox, the bear, the stag, and the wild boar, have taken the place of the more formidable *feræ* of earlier days. Everything indeed indicates an amelioration in the condition of primeval man. No longer contented with rude chipped flints, we find him possessed of stone implements carefully ground and polished. His ornaments too, of bone and horn, attest an advance upon the rude ideas of his Palæolithic predecessors, while fragments of pottery prove how great was his advance in social culture. We find, too, that some respect was paid to the dead, and caves were given up to purposes of sepulture, the bodies being generally placed in a contracted position within a rock cavity, and preserved from the attacks of wild animals by the placing of large slabs of stone at the entrance.

As time proceeded we find indications of the gradual advance of mankind in arts and perhaps intelligence. Fragments of kitchen utensils and grinding stones prove him to have been no longer dependent upon the chase for his sole or chief means of support, while the pottery and implements indicate marked progress, until at last we arrive at a period when the caves were no longer used habitually as places of abode, but were made into temporary shelters probably from the attacks of enemies. Thus we find implements and ornaments of bronze and other metals, the workmanship of which indicates a high condition of culture, and finally we reach a time when the presence of Roman and other coins fixes the historic date of the cave occupation, when we may be sure it was not of a permanent kind.

Though we have confined ourselves for the most part to notices of the English caves, it must not be sup-

posed that these alone furnish objects of interest to the inquirer. We have already briefly referred to the quaint paintings discovered by Sir. T. Mitchell in the sandstone caves of Australia, and somewhat similar productions of rude uncultured art have been observed in South Africa, but the date of these is doubtless recent, though the present inhabitants appear to have no knowledge of their origin. But in eastern Australia have further been observed caves in the limestone rocks of the Blue Mountains, which contained fossil bones of great interest from the similarity which they bore to those of the animals still inhabiting that region. Amongst these were two gigantic species of kangaroo, stated by Professor Owen to have been at least one third larger than the largest kangaroo now known, while smaller species, differing to a greater or less extent from any now existing, as well as a burrowing wombat, a climbing phalanger, a dasyure, and other creatures resembling, yet not identical with the animals now inhabiting the continent of Australia, prove how vast must have been the changes which have occurred since these creatures occupied the region in which their remains are still preserved.

Though hitherto we have said but little of the caves of America, yet it is in that country that the most stupendous examples are to be found. In Kentucky, for instance, the sub-carboniferous limestone presents us with a most extraordinary series of caves, which extend through the counties of Christian, Edmonson, Grayson, Hart, Butler, Logan, Todd, and Trigg, in the second of which is the celebrated Mammoth Cave. This gigantic excavation extends, in its various explored ramifications, no less than 223 miles beneath the surface of the earth, the actual length of the cave being estimated at 150 miles, and Mr. Dale Owen has calculated that the average height and width of the passages being reckoned as seven feet, no less than 12,000,000 cubic yards of material have been gradually excavated by the slow passage of carbonic-acid laden water through the rock.

In these vast caverns are found strange creatures which are apparently specially adapted for their underground dwelling-place, and it is that these might be briefly described that the Mammoth Caves have been specially referred to. First amongst these is to be observed the curious fish to which the name of *Amblyopsis spelœus* has been given. These fish are of small size, the largest yet observed being five inches in length. They are white in color, and when swimming about at the surface in search of food have been compared to small aquatic ghosts. Their most striking peculiarity is, however, their complete blindness, which is accounted for by their having been for unnumbered generations cut off from the light of day. Nevertheless, the optic nerves seem to be as well developed as in other fishes, but the eyes are represented only by tiny black spots beneath the skin. Deprived of sight, the little *Amblyopsis* is compensated by its marvelous powers of hearing and feeling. Though swimming at the surface of the water, and easily seen, it is very difficult to catch, as the slightest noise causes it to turn suddenly down and hide itself beneath stones at the bottom. Its movements are very rapid, and it seems to be guided to its prey by tactile organs, apparently connected with folds of skin covering the head, which apprise it of the smallest motions in the water in its vicinity. This little fish is nearly related to the shore minnows and pickerels, and not, as might have been supposed, to fishes inhabiting rivers or fresh-water lakes. Though blind itself, another fish has sometimes been found in the stomach of the *Amblyopsis*, possessed of well-developed eyes, and of a dark blackish color, but whether this is confined exclusively to caves seems

yet uncertain. Other blind fish have, however, been met with in caves. In the caves of Cuba have been found two species of *Lucifuga*, which possess no external eyes, but are furnished with minute hair-like organs of touch which doubtless amply supply their place. These, like the *Amblyopsis*, find their nearest allies in marine forms of fishes, though they bear some relation to the fresh-water ling of America. And again, in the Wyandotte Cave have been found two fishes belonging to the same family, one totally blind, the other with well-developed eyes, both of which find their nearest relatives in the waters of the sea. It has, therefore, been conjectured that the caves were originally occupied by salt water, and that their present inhabitants are survivors from an early period—perhaps the close of the Pliocene era.

In the American caves we have no notice of the existence of reptiles specially adapted for an underground life, but from a cave in the vicinity of Adelsburg has been obtained a species of salamander which appears to be entirely confined to the cave, and which is the solitary representative of the vertebrata in the cave-fauna of Europe. But of the lower animals there are many examples. In the Mammoth Cave is found a small blind crayfish, in which the eyes of the adult are quite rudimentary, while in the young they are fairly developed, though useless, thus leading to the conclusion that blindness was first "acquired" by old individuals, and by them transmitted to their offspring. In the caves both of America and of Europe have been found specimens of Isopod crustaceans, which seem to be almost if not quite identical. These creatures belong to the same group of animals as the familiar wood-lice of our gardens, but the nearest allies of the cave species are to be found in the genus Idotea, which is confined with one or two peculiar exceptions to salt water, so that here again we find reason to believe that the caves have at one time been submerged beneath the sea, as we do to some extent in the caves both of Europe and America in the presence of a little creature resembling the common sand-hopper (*Gammarus*) of our coasts, though some species are also to be met with in fresh water. Though several insects have been found in the American caves, it is hard to say whether they are all confined to such habitations. Two species of flies were found in the Mammoth Cave, at a distance of three or four miles from the entrance, but as these were brightly-colored and possessed well-developed eyes they may have been accidental visitants. Two wingless grasshoppers from the same cave also possessed eyes, but two beetles were totally blind. One, a *Carabus*, was of a pale reddish horn-color, and apparently had no trace of eyes, while the other, a Silphid or burying beetle, was of a greyish-brown color, and showed two small whitish spots, which have been very doubtfully regarded as rudimentary eyes.

Both in the Mammoth and Adelsburg caves small eyeless spiders have been found, and in the former a single species of Myriapod was discovered, the body of which was clothed with fine hairs which have been supposed to be organs of touch, though perhaps on insufficient grounds.

These blind inhabitants of caves from which daylight is for ever banished are peculiarly interesting as showing how greatly living creatures are influenced by the nature of their surroundings, for we cannot suppose that these animals have always been blind, and we can account for the presence of rudimentary eyes in so many of them only by supposing that their remote ancestors possessed these organs in their full development, and gradually lost them through disuse. Thus from whatever aspect we regard these interesting natural excavations they are fraught with intense interest.

The history of their formation alone would occupy a volume, while their contents, both animate and inanimate, open out to us a new page in the story of the earth's long history, much of which yet remains to be deciphered.

CONTENTS.

No. 33. **Vignettes from Nature.** By Grant Allen.

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No. 35. **Oriental Religions.** By John Caird, Pres. Univ. Glasgow, and Others.

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